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WORKSHOP PRACTICE

PRACTICAL WORK FOR THE DRAUGHTSMAN,
THE MECHANIC, THE PATTERN-MAKER, AND
THE FOUNDRYMAN

SECOND EDITION

EDITED BY
WILLIAM H. ATHERTON
M.Sc., M.I.Mech.E.

VOLUME I

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PREFACE

THROUGHOUT this work the subjects have been dealt with in a logical sequence which has been thought desirable for several reasons, chiefly because it enables the workshop employee to get a true perspective and co-ordinated view of the various engineering trades.

Although this first volume is of an introductory nature, it contains a large amount of information of value to every engineering works employee.

Following an Introductory Survey (Section I) comes Section II, which describes the mode of operation, construction, and use of the hand tools employed in workshops.

Drawing and sketching is dealt with in Section III, where all the principles are clearly outlined, and the relationship between the drawing office and the shops fully explained.

The last section treats of the properties of metals—ferrous and non-ferrous.

In a few words, the present volume deals with the fundamentals of modern workshop practice, and is intended for the young engineer who wishes to make himself familiar with all aspects of practical engineering work.

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SECTION I

INTRODUCTORY SURVEY

BY

THE GENERAL EDITOR

WILLIAM H. ATHERTON

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SECTION I

INTRODUCTORY SURVEY

THE prime object of this general survey of mechanical engineering operations is to promote the continuity and linking up of the eight volumes of "Workshop Practice," by making suitable references to the appropriate sections in the course of a systematic tour through the various departments of a large general engineering works from the drawing office to the erecting shop. In this survey the opportunity will be taken of directing attention to certain matters which would otherwise be overlooked or regarded by many junior engineers as of minor interest and importance.

The non-technical or purely business correspondence, and also the wages and accounting departments (usually housed in the general office), are not supervised by the works manager, but are under the general supervision of the secretary, who may possibly be also a commercial or financial director of the company. In any case the secretary normally attends all the directors' meetings and afterwards writes the minutes of the business discussed.

THE DRAWING OFFICE

When an engineering firm receives an order for a machine or a plant from a customer, the sales manager reads it through and acknowledges its receipt in a suitable letter; in addition to which a formal contract may have to be prepared and signed by both parties. Sometimes printed forms are used.

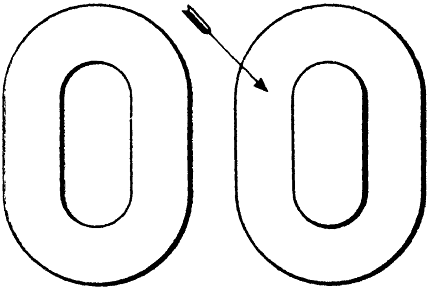
The order then receives a serial number, by which it is afterwards known, and a typed copy is passed to the chief draughtsman—the official in charge of the drawing office. A large contract comprising several units may be subdivided into many working numbers. The chief obtains from the estimating department a copy of the tender or quotation submitted, also a detailed list of quantities, and then discusses the job with the particular draughtsman chosen to see it through the drawing office. If it is a big job, then several other men will collaborate with him.

The time needed to complete the drawings, order the materials, and prepare the shop specifications may be anything from a few days up to several months, according to the magnitude and complexity of the contract. A repetition order for a standard machine can be put through in a few hours; whereas a special plant involves much designing, submission of drawings, alterations and other delays, before final approval of the detail drawings can be secured and the work put in hand in the shops.

A small office contains perhaps six draughtsmen, a couple of youths, and a girl tracer; whereas the drawing office of a big progressive firm may employ a staff of possibly a hundred, including juniors, plus perhaps twenty girl tracers in an adjoining office. Add to these the staff of the print room, also the drawing and photographic stores, and we reach a substantial total of office personnel. All this is in addition to the estimating department.

These office people are far from being a needless extravagance, but are essential elements of a good organization. In the long run it does not pay to run a drawing office on parsimonious lines. The fullness, clearness, and intelligibility of workshop drawings are most important requirements. A saving of an hour in the time of a girl tracer getting 50s. a week or so may easily mean a loss of two hours or more in the time of a skilled mechanic earning double that amount or more.

The method of making mechanical drawings is described in Section III of this work, which gives the essentials of the subject of mechanical drawing. General guidance in designing machinery and drawing office practice will be found in Atherton's *Mechanical Engineering*, a small book published by Pitman.



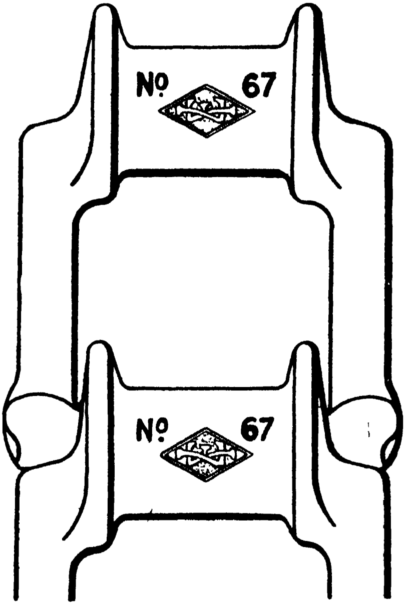
Showing a Recess in the Middle.

Showing a Projection in the Middle.

FIG. 1

The representation of breaks on page 144 of the present volume adds to the clearness of a drawing, since an oblique section serves at once to distinguish between a channel and a joist, even in a single view. Similarly the difference between steel flats and angles is indicated at a glance by the aid of oblique sections.

The conventional use of heavy shade lines, as in Fig. 1, is very helpful in distinguishing between holes and projections. A strong light is supposed to be shining in the direction of the arrow. Parts of the object represented are then thrown in the shade, these parts being more simply represented by thick lines than by cast shadows. This merit is further seen in Fig. 2, showing a malleable iron chain link. The adoption of shade lines is specially important in making drawings for reproduction in books and lantern slides. They ought to be more generally observed, despite the little extra trouble involved. This practice is not common, however, in the case of detail shop drawings.



EWART CHAIN
FIG. 2

In reference to *freehand sketching* a few hints will not be out of place here. When opportunity permits, it is a good plan for an apprentice to sketch the details of any machine in course of construction in the shops and to assemble them in a complete drawing at home. This method has the advantage of giving practice in freehand sketching as well as in instrumental drawing.

Before the writer is a scale drawing of a vertical drilling machine (in two elevations, plan and section) made at the age of 16 during his leisure hours, after starting work at 6 a.m. in the shops, the foreman having given him permission to make fully-dimensional freehand sketches of this machine after normal working hours. Obviously this was far better practice than merely copying existing drawings, as well as much more interesting. Another existing drawing (made a little later under similar conditions) shows the tool-box and slide-rest of a side planing machine in several sectional views. Such sectional drawings, it must be emphasized, are far more useful than external views in showing the actual construction of machines. In the case of symmetrical work, however, a composite drawing, half in elevation and half in section, may be utilized with advantage.

In illustration of the method advocated, of building up details to form assemblies, reference should be made to the assembly drawing of a lathe headstock given on page 175 and to the details on pages 170, 172, and 174.

When making mechanical drawings it is well to avoid a lot of dotted work by freely showing sections in firm, bold lines. One should get in the habit also of making good bold figures that are easily read.

A few words now as to modern drawing-office equipment. The type of drawing board preferred in modern offices is the space-saving balanced vertical type, as opposed to the old horizontal kind, though many of the latter boards are still in use, and are more convenient when tracing and writing. Actually both the angle and the height of the new sort of board are adjustable to suit the work in hand.

Moreover, instead of a loose T-square, a positively-guided sliding square is fitted, which cannot fall off the board; and it carries a narrow shelf to hold the instruments. A time-saving addition is a double scale-holder, which accommodates both a horizontal and a vertical scale at the same time, so that they are always immediately available. The initial cost of these modern appliances, though, is naturally considerable.

Tracers, however, retain the old type of drawing board, held at a slight angle by packing pieces; and they mostly stand to their work. A nearly vertical board is not suitable when tracing, or when inking in, a drawing, as the ink does not flow readily.

For the guidance of pattern-makers, machinists, and erectors, one usually sends into the shops a blue print, having white lines on a blue ground, preferably mounted on a board or else attached to a stick, on which it is rolled. Loose prints are apt to get dirty and torn when left lying about benches and machines.

The colouring of working drawings is less practised now than formerly, though it is still desirable to be able to produce a highly-finished coloured drawing for special occasions, including exhibitions and competitions. Furthermore, a good blue line print on a white ground, having the sections coloured with appropriate flat washes and the elevations edged with a faint wash of colour, is so wonderfully clear as to be a real pleasure to work to. The same is true of a cloth tracing coloured on the back. A quick alternative to brushwork is to crosshatch the sections freehand with coloured crayons.

THE PURCHASING DEPARTMENT

The purchasing department of an engineering works is presided over by a purchasing manager, or head buyer, who works in close association with the drawing office in buying raw materials such as steel plates and sections and also finished parts such as electric motors and speed-reducing gears.

No engineering firm makes everything it sells, but buys many parts better and more cheaply from specialists manufacturing in huge quantities, thus keeping their machinery and men fully employed on repetition work. Some firms indeed have no foundry of their own, but buy all castings from outside foundries.

Quotations for supplies are commonly obtained from more than one firm, acceptance or refusal of tenders being governed by considerations of quality, price, time of delivery required, and the reputation of the firm as to reliability in carrying out its promises. Printed forms are much used in order to save time and ensure uniformity in duplication.

An efficient head buyer needs a wide knowledge of materials and markets. If not a trained engineer himself, he should be controlled by a technical expert, such as the manager or the production engineer, otherwise he is apt to be influenced too much by price alone to the detriment of quality and service.

THE WORKS LABORATORY

Attached to all first-class modern engineering works and foundries is the laboratory, which is controlled by the chief metallurgist and scientific expert, a very important official. Besides chemical and optical apparatus, this department contains machines for testing the strength and ductility of materials in the form of test pieces, and also their hardness and resistance to fatigue.

In order to ensure the scientific control of the quality of the work, the laboratory staff analyses selected raw materials as well as samples of the products. Chemical tests may also be made to determine the corrosion resistances of materials of varying composition.

In well-equipped malleable iron foundries, analyses are continually being made regarding the carbon, silicon, sulphur, and manganese contents of the available pig irons, as well as rapid working tests of the daily product.

The duties of the chief metallurgist also include the supervision of furnace operations and temperatures, as well as the selection of suitable mixtures of pig iron, scrap and steel in order to produce the desired analysis of the castings.

Several test pieces cast from each melt are heat-treated in different parts of the annealing ovens, and afterwards tested both mechanically and microscopically. This information is filed systematically, along with pyrometric records of the annealing process, the figures being plotted daily. The proper control of the temperature during annealing is extremely important, and this is aided by means of self-recording electric pyrometers.

Of vital importance to the mechanical engineer is the careful study of various metals, especially iron and steel, which are classed as the ferrous metals, *ferrum* being the Latin name for iron. These are dealt with in Section IVB of this volume and also in Sections VIII and IX of Volume III.

The other metals of interest to the engineer, classed as non-ferrous metals, as well as numerous alloys, are dealt with in Section IVA, as regards their composition, physical properties, and engineering applications.

Sometimes a distinction is drawn by engineers between the "mechanical" and the "physical" properties of metals; though this fine distinction is not generally observed, "physical properties" commonly meaning all characteristics other than purely chemical ones.

Certain authorities, however, prefer to class as mechanical properties only the ultimate tensile strength, the yield point, the elongation and the hardness of materials. The physical properties then become the density, specific heat, melting-point, coefficient of expansion, heat conductivity, modulus of elasticity, electric resistivity, and magnetic characteristics. On the other hand, corrodibility is a "chemical" property. The combination of good mechanical properties with high resistance to corrosion produces a material of great utility. Good resistance to repeated shocks is also a valuable property in which wrought iron and blackheart malleable iron excel.

In the laboratory much use is made of the microscope for studying the internal grain structure of metals, as revealed by various magnifications ranging from 50 to 1000 diameters and seen in micrographs of iron and steel samples. Many photographic reproductions of these (apart from colour) are given in Sections IVB and VIII, which deserve careful study and comparison on account of their metallurgical interest. The full meaning of these highly enlarged photographs is not obvious at a glance. They may be compared with the contrasted micrographs of abrasives on page 167 of Volume IV.

THE PATTERN SHOP

This is an important department of a general engineering works, usually annexed to the foundry, though not all engineering works possess either a pattern shop or a foundry, some works buying both patterns and castings from outside sources. Indeed, castings in steel, or in malleable iron, or in brass and other alloys, are commonly bought from specialist firms.

There is a vast difference between the solidity and finish of various patterns. Those for repetition work, requiring thousands of castings "off," are of the most permanent construction; whereas many patterns for jobbing work, needing only one or two castings off, are of a cheap and temporary character, as they will never be used again.

The methods of producing patterns from various materials are described in Section V (Volume II), and also the usual pattern-shop machines employed for their construction in a well-equipped shop. The basic hand tools used by pattern-makers are dealt with in Section II. The jointing of patterns in order to give easy delivery from the sand is considered at page 25 in Section V.

Blue prints are sent from the drawing office to the pattern shop to be translated into full-sized patterns, or models, for the use of moulders in the foundry, before much progress in the production of a machine can be made elsewhere.

A pattern-maker does not work to an ordinary two-foot rule, however, but uses a special contraction rule which is made about $\frac{1}{8}$ in. per foot longer than the standard rule, to allow for the shrinkage of the metal during cooling in the mould; for otherwise the cold casting would be too small in all its dimensions. Yet contraction is not really uniform throughout a casting, and this rather complex matter of variable pattern allowances is dealt with at some length on page 16 in Section V. The actual contraction is rather more for steel, malleable iron, and brass than for grey iron castings.

Core-boxes in wood or in brass are also made in the pattern shop. From them the necessary sand cores are prepared in the core shop, these cores usually representing the cavities or hollow parts of the castings; though this is not always the case, as explained on page 160 in Section VI. The making of core-boxes and from them the production of sand cores is dealt with at page 69 in Section V, and this important subject is further developed at page 160 in Section VI.

In all repetition work much use is made of metal patterns (usually either brass or aluminium) in connection with moulding machines. In large establishments there is a separate department known as the "metal pattern shop," which is equipped with a great variety of light machine and hand tools for exact work, a metal pattern-maker being a highly skilled craftsman.

In this connection attention is directed to the subject of pattern plates, for the economical production of numerous castings by the process of plate moulding, a method that enjoys great favour in light foundries engaged on repetition work. Metal plates are preferable to wood, and are often made of aluminium for the sake of lightness. This important subject is dealt with at some length on page 80 in Section V.

When going through a pattern shop one should mentally note the essential equipment of machines and tools, and also carefully observe the various processes involved in the actual construction of patterns and core-boxes. The "core prints," or projections on patterns left to locate the cores, are always coloured differently from the patterns themselves. They form anchorages in the mould, which retain the dry-sand cores in their correct positions.

On completion of the pattern a special label is attached to it, stating the name of the customer and the number of castings wanted, as well as other information, before being passed on to the foundry. Core-boxes, however, go to the core shop, which may have either a separate foreman or be under the supervision of the foundry foreman. Large firms have a superintendent or foundry manager and several foremen under him controlling different sections of one big foundry or several smaller ones.

THE CORE SHOP

There are at least two important matters which have to be studied in a core shop. The first of these is the preparation of the sand by the addition of various binders and thorough mixing, a matter that is discussed in Section VI at page 165. The second is the construction of core-drying stoves of both fixed and continuous types.

Gas coke is the most common fuel, though powdered coal (and sometimes gas) is also used for firing these "stoves" or "core ovens." The green-sand cores go into the stove soft and are easily damaged, but come out fairly hard yet porous.

In light work pneumatic bumpers are useful for consolidating the sand in metal core-boxes instead of hand ramming, girl labour being employed. In rather larger work core-blowing machines operated by lads are helpful in rapidly producing numerous cores ready for baking in continuous stoves, so as to make them firm enough for safe handling.

A quite different technique is necessary for making the large loam cores used in heavy foundries for steam cylinders, as described in Section VI at page 171. The ventilation or "venting" of such cores is a matter of vital importance, in order to permit the escape of the gases generated when molten metal is poured into the mould, and thus prevent the formation of blowholes. For the same reason the proper venting of the body of the mould is important. The making of cores and moulds for loam moulding is considered at some length in Section VI at page 152.

THE FOUNDRY

Before entering into a mass of detail regarding foundry work, one should realize that the operations in and about a moulding shop, or foundry, consist broadly of the following six processes—

(1) Preparation of the sand for cores and moulds.
(2) Making of cores by the aid of core-boxes.

(3) Making of moulds by the aid of patterns, flasks, and machines.

(4) Mixing and melting of metal in a suitable furnace.

(5) Pouring of the molten metal into ladles and then into moulds.

(6) Removal of the castings from the moulds, knocking off the sprues, and cleaning, trimming, or fettling the castings.

Sand. The first raw material required in a foundry is moulding sand, the selection and preparation of which is dealt with in Section VI at page 132. Moulding sand must be of a more clinging nature than the sea or river sand often used for making cores. There must be sufficient clay present as a bond to enable the sand to hold together when squeezed.

Moulding sand is divided into facing sand, for the smooth finish of the mould in contact with the pattern, and floor sand (or backing sand), which is partly-used sand, or burnt sand. Some of the old or spent sand has to be rejected daily, and hundreds of tons got rid of weekly, to a dump outside the works often situated miles away from the foundry. This necessitates much expense in the transport and disposal of the waste sand, and even the occasional purchase of low-lying land to be filled up to normal level by tipping foundry "rammel" upon it. Eventually this land may be sold as a building site.

Every large foundry producing repetition work is equipped with an extensive sand-preparing plant, comprising a sand mill, bucket elevator, screen, and magnetic separator, where old and new sand are mixed and tempered with a suitable admixture of water. In fact there may be several of such plants or their equivalents.

The loam used for heavy foundry work is a mixture of moulding sand and some refuse fibrous material.

Loam moulding is a special branch of the moulder's art, needing much skill and experience. It is dealt with in Section VI at page 152.

A distinction is made between green-sand and dry-sand moulds. "Green" here means simply damp moulding sand which has been properly rammed. The drying, or baking, of moulds is a serious hindrance to rapid production, and is not necessary in light work, though essential in respect of many large deep castings. Skin-dried moulds are intermediate between green-sand moulds and the dry-sand moulds, which are dried completely in stoves before hot metal is poured into them.

The sand used for dry-sand moulds is more cohesive or tenacious than green-sand, and is rammed harder. Thorough drying increases the porosity of the sand and improves the venting, while the mould is firmer and less likely to yield to liquid pressure.

Flasks or Boxes. An ample supply of moulding boxes, or flasks, is a necessity in a foundry. These vary greatly in size from about 12 in. square up to several feet long, according to the nature of the work done in the particular foundry. For general work boxes are made of cast iron, with crossbars to support the sand; but for lighter work pressed steel flasks are favoured to an increasing extent in repetition foundries, on account of their lightness.

Wooden snap-flasks find application for very small work. They are hinged at one corner, and have a snap catch at the opposite corner. When the mould is made, usually on a machine, the flask is opened and the mould (resting on a bottom board) is put down on the floor, forming one of a row of moulds, ready for pouring.

Although two-part boxes are most common, yet three-part boxes are made use of for specially deep moulds. The bottom box is known as the "drag," the top box as the "cope," and intermediate boxes without crossbars as "middles," or in America as "cheeks" (see Figs. 11 to 13, page 142, Section VI). Circular flasks are often used for round work. Small boxes have handles, and large boxes have trunnions as well as handles, for turning over when slung from a crane.

Box parts are registered and held together by pins and holes drilled in the lugs. In moulding, some facing sand is first added in contact with the pattern, and the box is then filled up with floor sand and rammed. Before casting, the cope is usually loaded with weights to prevent lifting as the metal is poured.

MOULDER'S HAND TOOLS AND APPLIANCES

Besides the ordinary round hand "riddle" used for removing bits of metal, wire, and lumps from facing sand, there are also available in some foundries motor-driven riddles, suspended overhead, for dealing with larger quantities of sand.

Several types of "hand rammers," both rounded and wedge shaped, are utilized for packing or consolidating the sand in the flask around the pattern. The inverted handle end of a shovel, too, is often made use of by moulders as a convenient rammer. "Pneumatic rammers" are also available in some modern foundries, where compressed air is laid on to moulding machines and air lifts. Vent wires are needed for piercing the rammed sand with vent holes, to permit the escape of gases when hot metal is being poured into the mould.

Amongst hand tools used for finishing moulds are "trowels" in several shapes and sizes, while double-ended "slicks" or "sleekers" of many forms are useful for repairing and smoothing surfaces. Brushes or "swabs" are used to moisten with water the edges of the sand round about a pattern. (See Section VI, page 182.)

Iron "chills" are often applied to moulds, in an attempt to secure a quicker rate of cooling of the thicker parts of castings, and so prevent unsoundness, as mentioned in Section VI at page 178 and again referred to at page 228. The correct use of chills in the foundry is a matter of considerable importance.

PIPE MOULDING

The process of centrifugal casting has been developed on a large scale by firms specializing in the production of cast-iron pipes, such as the Stanton Ironworks Co. Ltd. and the Stavely Iron Co. Ltd. Pipes cast centrifugally in rotating iron moulds have a better finish and a more uniform thickness than common pipes. They can also be made in longer lengths, thus saving the cost of many joints, and are therefore more economical.

MOULDING MACHINES

In foundries doing much repetition work, many types of moulding machines are extensively utilized for economical production. Some of them are operated by hand, but more by air pressure; while others use water pressure, and some machines rely on a current of electricity. But rarely, if ever, are both pneumatic and hydraulic moulding machines installed in the same foundry. Magnetic moulding machines are the latest development, but are rather expensive.

Several types of moulding machines are briefly described in Section VI at page 183. The threc main divisions are: "squeezers" for small shallow work, "jar" or "jolt ram" machines for heavier and deeper work, and "sand slingers" for medium deep work. These machines utilize the three methods of squeezing, shaking, and throwing sand, in order to consolidate it firmly against the pattern. Other machines for deep moulds combine the jolt and the squeeze principles.

Such machines enable repetition work to be done rapidly by semi-skilled labour, a long apprenticeship not being needed to learn their use. Moreover, greater uniformity of moulds is secured than is feasible by hand-ramming, combined with a lower cost of production.

THE MELTING OF IRON

After sand the next raw material of the iron founder is pig iron and scrap iron. A great part of the metal melted in a "cupola" (or vertical cylindrical type of furnace) is not new pig iron, but is added in the form of broken up old castings and waster castings, together with runners and headers broken off new castings as they leave the sand moulds. The same is true of the metal melted in the "reverberatory" or horizontal type of furnace depicted in Fig. 3 (popularly known as an air furnace), which is so much employed in foundries producing blackheart malleable iron. Alongside the furnace is seen an electric accumulator truck equipped with a tipping body for carrying hard furnace coal.

Crucible furnaces are now utilized for melting only on a comparatively small scale, whether in steel, malleable iron, or brass foundries. The important subject of melting equipment is referred to in Section VII at page 206, including remarks on the relative merits of coke, gas, and oil as fuels, also of electric furnaces, as employed in non-ferrous foundries.

In Section VI, on iron and steel founding, the "cupola" form of furnace is described at page 112 and outlined in Fig. 1 on page 114 with the addition of a receiver. This receiver also acts as a mixer, from which molten metal is tapped into ladles; and it permits of more continuous casting. The ordinary cupola, however, is not fitted with a receiver.

Although the cupola is a more economical melter of

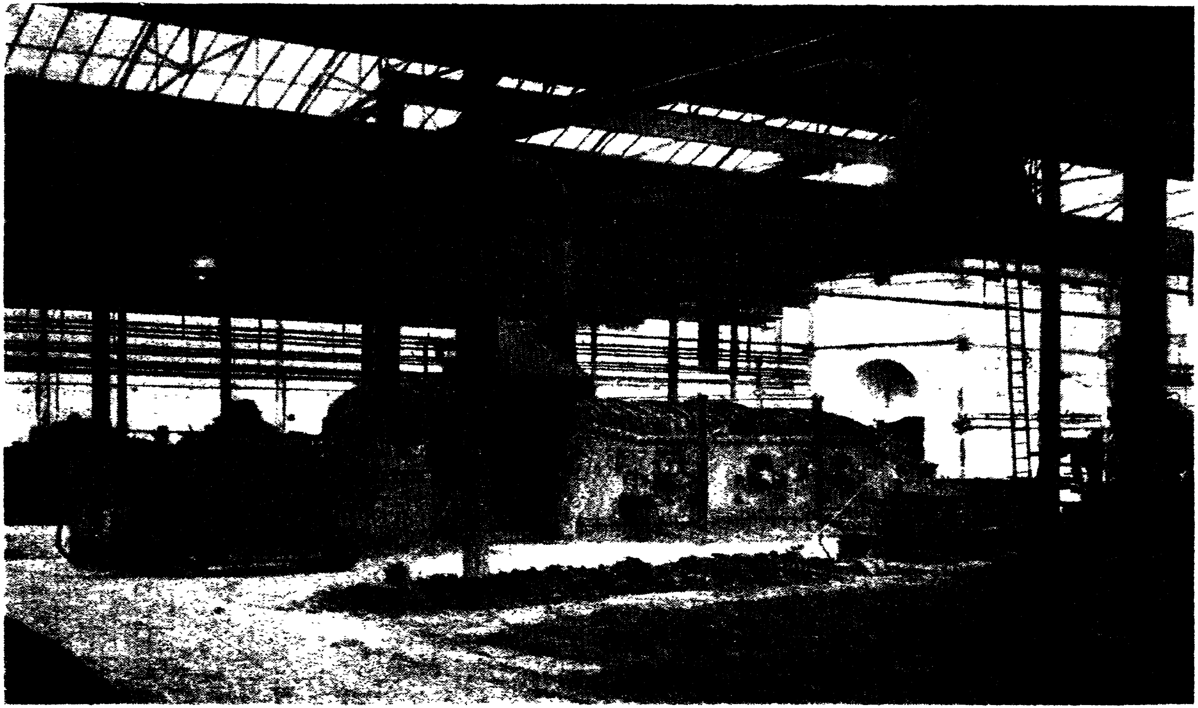


FIG. 3. COAL-FIRED MELTING FURNACE

iron than any other type of furnace, unfortunately it has the drawback of imparting sulphur and other impurities to the molten metal in contact with the coke. The presence of hot coke, moreover, makes impossible the production of iron low in carbon. Hence the cupola is not used in foundries making blackheart malleable iron, where low sulphur and low carbon are both essential. Yet the cupola is commonly employed in the production of high-sulphur, i.e. "whiteheart," malleable iron castings.

The true thermal efficiency of a furnace is the ratio of the heat utilized to the heat that would be generated by the perfect combustion of the fuel. It is hardly possible to determine this ratio, however, though it seldom reaches 50 per cent. But the practical measure of the efficiency of a cupola is the so-called "melting ratio." Thus if 6 tons of iron are melted by the combustion of 1 ton of furnace coke, then the melting ratio is 6.

In the case of the long 20-ton air furnace employed in recent malleable foundries not more than 3 tons of iron are melted per ton of pulverized coal burnt, as the thermal efficiency is only low. Yet this is a successful form of furnace, especially when much of the heat in the escaping gases is utilized for the production of steam in a waste-heat boiler, as is customary.

The "rotary furnace" known as the Brackelsberg is a modern alternative to an "air furnace," and is favoured for melting small heats, such as 5 tons. It may be fired by either oil or finely powdered coal. The thermal efficiency is fairly high.

STEEL MELTING FURNACES

At least three other forms of melting furnace have to be considered, more especially in relation to steel foundries. The first of these is the "open-hearth" gas-fired regenerative furnace, as described on page 122 and illustrated on page 123 of Volume II. It is suitable for big heats and heavy castings, though used mainly for making steel ingots. The producer gas and the air required for its combustion are both preheated to about 1,000° C., thus improving the thermal efficiency and enabling high temperatures to be reached. As the supplies of gas and air are both under control, one can get either neutral, or oxidizing, or reducing flames at pleasure, according to requirements.

In common use in steel foundries are also various modifications of the original "Bessemer converter" as illustrated in Section VIII at page 5, with its bottom tuyères, through which air is blown at a pressure of about 20 lb. per sq. in. The metal is first melted in a cupola, then run into a converter mounted on side trunnions, to permit of tilting, and finally brought up to temperature by the internal combustion or oxidation of the surplus carbon, silicon, and other elements. Some 8 per cent of "spiegel" is afterwards added to give the required composition, or a smaller quantity of the much richer ferro-manganese.

The baby side-blown "Tropenas converter," introduced about 1891, is favoured in steel foundries of average capacity. A good quality of low-carbon steel is produced by it, suitable for small and medium castings, as the steel is run very hot and fluid. The low air pressure of 3 lb. per sq. in. is sufficient for its operation, as the blast acts horizontally on the surface of the metal instead of being blown through the molten bath from below.

A good account of the Tropenas process will be found at page 75 of *Steel Manufacture Simply Explained*, by Simons and Gregory,* where a Tropenas converter is illustrated measuring some 5 ft. in diameter and 9 ft.

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* Published by Sir Isaac Pitman & Sons, Ltd.

high. The lining is ganister, which is mainly silica cemented with fireclay.

An objection raised to side-blown converters in general is that much iron is wasted in the blowing operation, though the loss of iron by oxidation is not more than 1½ per cent actually.

An interesting form of oil-fired converter is shown on page 122 of Section VI. This so-called "Stock" converter is independent of the usual pre-melting cupola, and it is also fitted with an air-heater, in order to improve the thermal efficiency of the plant.

Finally, there are several types of furnaces utilizing electricity as the source of heat. The most common of these is the "electric arc furnace," having movable carbon electrodes for conveying the current. It is made capable of being tilted through a considerable angle, in order to discharge its molten contents readily. An example of this type of furnace is described and illustrated in the same section at page 121, as adapted to the needs of a foundry making steel castings.

The Héroult direct arc furnace has three electrodes, the electric arcs forming between their ends and the metal being melted, which is usually steel scrap. The current traverses the surface of the metal and returns to the transformers.

The arc furnace gives the highest temperature that can be obtained by any form of melting furnace. It produces steel of high fluidity extremely low in sulphur and of any desired carbon content.

Electric steel is favoured in the automobile and aircraft industries for engine details, especially those made of alloy steels having high mechanical properties of great uniformity.

The horizontal rocking form of "indirect arc furnace" is made only in small sizes. Here the electrodes enter at each end of the cylindrical furnace and meet in the middle to produce an electric arc, which heats the wall of the furnace by radiation. The slow rocking motion then heats the metal from the hot wall. or furnace lining, and also stirs the metal and improves the rate of melting.

Melting iron by means of an electric current is really too expensive a method to use in ordinary grey iron foundries. In some special foundries. however, the charge is first melted in a cupola and then transferred into an electric arc furnace for superheating. This is done only when an iron of superior quality is required, as in a few malleable iron foundries. Current must be exceptionally cheap before it becomes possible to use electric furnaces economically for the actual melting of cast iron in ordinary foundries.

REFRACTORIES

In all furnace work the question of heat-resistant materials is of vital importance, their destruction by wear and melting being very heavy and costly at high temperatures. "Graphite," or crystallized carbon, is a highly refractory material of simple chemical composition. When mixed with fireclay it is employed for making crucibles, though plain fireclay is the material more commonly used for this purpose.

Clay is essentially a compound of the oxide of silicon (silica) with the oxide of aluminium (alumina) plus various impurities. "Fireclay" is therefore aluminium silicate with traces of impurities and some water. Stourbridge fireclay is said to contain some 64 per cent of silica, 23 per cent of alumina, 2 per cent of iron oxide, 1 per cent of calcium, and 10 per cent of water. When mixed with double its bulk of silica sand it is used for daubing cupolas and ladles.

Firebricks are of various kinds, no one kind of brick being suitable for lining every class of furnace. Yet all good firebricks contain very low percentages of the alkalis lime, potash, and soda, as their presence increases fusibility. Silica bricks are suitable for the walls and roofs of the reverberatory furnaces used in malleable iron foundries, the furnace temperature being about 1600° C. Silica sand is used for the beds of such furnaces, where it sinters over and lasts for about ten heats. The bricks in the furnace walls may have a useful life of a dozen or more heats. On this work aluminous brick is quite 15 per cent more durable than ordinary good firebrick.

Analyses of Firebricks. The approximate average composition of four varieties of refractory bricks is given in the table below—

Oxides	Common %	Silica %	Aluminous %	Magnesite %
Silica (SiO_2) . .	53	95	48	2·5
Alumina (Al_2O_3) .	40	1	44	2·6
Iron oxide (Fe_2O_3)	2·7	1	2	4·4
Titanic oxide (TiO_2)	1·6	Trace	3	Trace
Lime (CaO) .	0·3	1·6	1	Trace
Magnesia (MgO) .	0·7	0·3	0·4	90
Alkalis . .	1·3	0·5	1·4	0·2

"Ganister" is a highly silicious lining for Bessemer converters, furnaces, and steel moulds, containing some 90 per cent of silica. When phosphorus is present in the iron, ganister cannot be used as a lining for converters, dolomite (magnesian limestone) being substituted. In the "after-blow" of the process the phosphorus is then removed in the slag in the form of phosphate of lime, this being the special feature of the basic method of producing steel, as described in Section VIII at page 4.

THE HEAT TREATMENT SHOP

Annealing. After grey iron and brass castings have been removed from the sand, thoroughly cleaned and fettled by chipping and rough grinding, they are normally ready to go to the machine shop for subsequent operations. But not so as regards *steel* castings, and still less so as regards the white iron castings from which malleable castings are produced. These have to be annealed, or subjected to extensive heat treatment, before being in a fit state for machining, after passing through the fettling and straightening shops.

This annealing process may occupy as long as three days in the case of steel castings, and more than double that time in the case of the malleable iron castings which are so largely used in the manufacture of motor vehicles, both light and heavy. The result of the annealing is a most useful product, which is machined at a high speed, is tough, and is capable of withstanding repeated shocks without suffering undue fatigue.

The influence of annealing on steel is graphically shown by the series of curves on page 16 of Section VIII, where the full lines refer to strength and the dotted lines to the property of ductility, as indicated by the elongation of test pieces under a tensile force.

A good quality of mild steel under test will stretch as much as 50 per cent after annealing, while a well-annealed blackheart malleable iron test piece will give an elongation of about 20 per cent. Good whiteheart malleable cast iron shows an elongation below 10 per cent.

Some remarks on the short-period annealing of forged steel details will be found in Section IX at page 92, the object of this process being to refine the grain structure of the steel.

It is curious that manganese steel chain pins, as used on heavy bucket elevators, are annealed by heating to a red heat and then immersing them in cold water. The result is surprising, as one would naturally expect that this drastic treatment would harden them, as in the case of carbon steel pins.

Hardening. Although softness, or rather easy machinability, is a most desirable quality in a metal from the viewpoint of a turner or a driller, as enabling him to get through his work rapidly without spoiling his tools, yet the suitability of the material for its duty in the complete machine is far more important. Hence many details, such as pins and shafts, must be hardened before use, in order to gain the necessary durability. Other details have to be treated to give greatly increased strength and suitability for their particular duty.

This matter of the hardening and tempering of steels in various ways is dealt with in Section IX, which also includes an account of the modern method of case-hardening steels by immersing the already heated details in a hot bath of sodium cyanide (NaCN) for a sufficient length of time to enable carbon to be absorbed, and then quenching them in a deep tank of oil kept fairly cool by an external cooler. The thickness of the hard carbonized case can be gauged by a special lens fitted with an illuminated scale.

This method has been extensively adopted for the case-hardening of the 2 per cent nickel steel pins as well as the malleable iron links used for the caterpillar tracks of various military vehicles. Circular gas-fired furnaces are utilized. The sodium cyanide is supplied as a white solid in sheet steel drums. The best case-hardening pots are made of nickel-chrome, and are guaranteed to have a life of 2500 hours at 950° C.

Additional notes on case-hardening will be found in

Section XXII on "Practical Blacksmithing"; while some practical guidance in hardening cutting tools is given in Section XIX on "Jigs and Tools."

THE SMITHY AND THE FORGE

Few machines, if indeed any, are ever built up entirely of cast parts, so that forgings as well as castings are necessary for their construction. Yet many of the smaller details (such as shafts, pins, and studs) can be made in the machine shop from rolled bars of steel, without the need for forgings. Also vast numbers of chain pins are made from bright bars by forming the pin head on a special heading machine, one end of the bars being first heated in a gas furnace.

The work of the blacksmith includes bending, upsetting, and welding, all of which operations are done on the anvil with the aid of tools of many kinds, as described in Section XXII. A good all-round blacksmith is a highly skilled craftsman of long experience.

For many years the vertical multiple-hammer type of short-stroke high-speed tool known as the Ryder forging machine was a favourite for producing spindles, bolts, pins, and studs, which have to be swaged down in various sizes by a succession of rapid blows; though this machine is certainly not used now to the same extent as formerly.

As regards power hammers, the spring type is convenient and suffices for small work, the pneumatic hammer is used for rather heavier jobs, while the steam hammer is required for the heaviest work done in a smithy. For making still heavier forgings, beyond the capacity of the ordinary smithy, hydraulic presses are utilized.

When large numbers of identical steel forgings are required it is usual to make them by the process of drop forging, or stamping in dies. This process is dealt with in Section XX, while the method of making the steel dies themselves is further detailed in Section XXI.

Although every engineering works possesses a "smithy" where miscellaneous light forgings are made, not every works has a "forge" where heavy work is done. Large forgings are usually bought out from forgemasters possessing special experience, facilities, and plant for turning out forgings of the heaviest class successfully and economically.

Such plant and equipment include suitable reheating furnaces, cranes, heavy hammers, and hydraulic presses. For the heaviest work forging presses are made in capacities ranging from 3000 to 10,000 tons, and are far more effective than big steam hammers. The largest presses are needed for heavy gun forgings. They work in conjunction with high-pressure hydraulic pumps, accumulators, and intensifiers. In the case of small hydraulic presses of modern design, high-speed short-stroke multiple-ram pumps force oil directly into the working cylinders of the presses, thus dispensing with accumulators.

THE MACHINE SHOP

After the necessary castings have been made in the foundry, then freed from sand, scale, fins, and other excrescences in the fitting shop, and suitably heat-treated as may be required, they are all transported into the machine shop, as also are the steel forgings produced in the smithy and the forge. Before they can be machined, however, many details have to be marked out with centre lines and limit lines on the marking-off table, by the aid of the scribing-block, steel rule, compasses, and other hand tools, as well as V-blocks, packing pieces, and angle plates.

The next stage in the construction of a machine is the accurate tooling of all the parts to the required dimensions: for which purpose numerous machine tools of different functions and capacities are necessary to carry out the various operations.

Lathes in great variety are wanted for turning round parts of either cylindrical or disc form, and also for boring holes and cutting screws. A standard lathe for general work bears the lengthy title of a "sliding, surfacing, and screw-cutting lathe," an example with a gap bed (to accommodate larger diameters) being illustrated on page 98 of Volume III. Such lathes are commonly made from 6-in. to 18-in. centres, swinging work ranging from 12 in. to 36 in. diameter. Smaller lathes are made for amateur and model work, as well as larger ones for specially heavy work. The bed may be any length from say 8 ft. to perhaps 40 ft., though gun lathes are even longer.

Many lathes, however, are used mainly for surfacing discs and for turning wheels of large diameter. These are known as "face lathes," having no tailstock but a very big face plate for holding the job. Lathes specially made for turning locomotive wheels are styled "wheel lathes." They have two headstocks and two slide-rests, for operating with two tools at the same time.

The process of cutting screws of single and multiple threads in a lathe is treated at some length in Section XI, including the mode of calculating the necessary change wheels for odd pitches.

Much information regarding lathe cutting tools is given on pages 142–153 of Volume III and on page 153 of Volume IV. Solid tools are now little used, however. Modern practice favours a small piece of special high-speed steel welded on to the body of the tool. Alternatively, one may use tool-holders, though they do not stand up so well to heavy cuts.

Other small high-speed lathes with hollow spindles (to accommodate long round bars) are very handy for turning quantities of studs, pins, and small rollers from bright steel bars as the raw material, without much setting. These machines are termed "capstan lathes" in the smaller sizes and "turret lathes" in the larger sizes, as the cutting tools are fixed in a multiple tool-holder which is capable of rotating about a vertical axis in the same manner as a turret supporting the big guns of a battleship (see page 123, Volume IV). Special turret lathes are made to deal with much heavier work than the ordinary light capstan lathe can tackle.

When the six tools in the turret have been properly set for a series of consecutive operations, an enormous saving in time and labour is effected. Production then proceeds apace for hour after hour, the rate of production far exceeding that possible with an ordinary slide-rest, with its inevitable interruptions to the progress of the job for setting the different tools repeatedly.

When the motions are all automatic for purely repetition work the tool almost ceases to be a turning lathe. It becomes an automatic machine of great complexity, run by a semi-skilled man and not by a skilled turner who has served a long apprenticeship to the trade. Examples of such "automatics," for making multitudes of small details from steel bars with a minimum of labour, are seen in Figs. 19 and 20 (pages 139–140 of Volume IV).

The rapid formation of somewhat complex contours (both stepped and curved) in small repetition work at a single operation, by means of form tools of suitable outline used in the lathe, is described at length in the tool-room section on page 270 of the same volume. Such "form tools" are often turned as a contoured disc and then suitably gashed to make a cutting edge.

The "vertical turning and boring mill" is an efficient alternative type of machine to the face lathe, and is used for similar duties, though so different in appearance. It is more convenient for the operator to fix the job on the horizontal table of a vertical turning mill than on the vertical face plate of a lathe, while it is also more accessible and in better view, especially for *internal* turning. Occasionally the table of such a machine is made up to 40 ft. diameter. It is driven through a variable speed gear, to enable the lineal cutting speed to be kept nearly constant, despite the great variation in diameter of the job in hand.

For smallish work the "duplex" or double-table machine shown on page 99 of Volume IV is useful, as two tools can often be kept in operation at the same time by one man, which tends to economy of time.

Vertical Drilling Machines are used for making round holes of comparatively small diameter, from $\frac{1}{8}$ in. upwards, and for tapping drilled holes, while boring machines produce holes of large diameter. Yet there is no exact line of demarcation between drilling and boring; though one seldom drills a hole bigger than 3 in. diameter, and most drills are employed in drilling holes of less than half that size (see Section XV).

Boring may be done on a large drilling machine, or in a lathe, or by means of a vertical boring mill, or on a horizontal boring machine.

The operation of slightly enlarging an existing cored hole on a drilling machine is termed "rhymering," while "reamering" is a rather more exact sizing operation; though this distinction is not always observed. This subject is dealt with fully on pages 34–41 of

Volume IV, several varieties of both fixed and expanding reamers being described.

For cutting a rather large hole in plates the operation of "trepanning" may be adopted. The term "trepan" comes from the mining industry, where enormous trepans are employed for sinking large circular boreholes and mine shafts. The tool leaves a core of solid material.

The most generally useful drilling machine is the "radial" type, on account of its adaptability and great range of capacity, a good example of one being pictured on pages 70–1 of the same volume, driven by a motor instead of a belt. A great variation of the speed of the drill spindle is needed, to suit holes of different sizes drilled in various materials, this being secured by means of a change speed gearbox on the saddle.

Suitable drilling speeds for brass, cast iron, and mild steel are given on page 15. Blackheart malleable cast iron is notoriously easy to machine, and for this well-annealed material the drill may be safely run at 50 per cent higher speeds than are customary for drilling grey cast iron.

"Boring bars" and tools are fully dealt with on pages 16–23, and also the method of facing large annular surfaces by means of a facing attachment on a boring bar, as shown on page 26, the two cutting tools being traversed radially by screws and star wheels.

For medium work the ordinary "upright drilling machine" depicted on page 66 is quite suitable, while the simple "pin drill" shown on page 63 is much used for the lightest class of work. "Multiple-spindle drilling machines" are special tools not used for general work. The main features of flat drills and of twist drills are explained on pages 4–11.

Repetition drilling is done with the aid of "jigs" to guide the drill, thus saving setting-out and ensuring uniformity. Jigs may be simple as on page 47, or complex as indicated on page 60.

Jigs and Fixtures. The study of jigs and fixtures is of great practical importance from the point of view of rapid production of repetition work and to secure the interchangeability of similar parts. In fact, a section of a works drawing office is often devoted to their design and a part of the tool room to their construction.

One may reasonably ask what is the difference between a jig and a fixture? Roughly speaking, a fixture is a rather elaborate jig. But there is a clearer distinction, though it is not always definitely observed. A jig is essentially a *guiding* device, whereas a fixture is essentially a *holding* and gripping device, besides being usually more elaborate than a jig. Parts of a fixture may be hinged. Frequently, however, the two functions of guiding the drill and keeping the job in the correct position are combined in one article which is still called a fixture. The term "box jig" is also used (see page 257, Volume IV).

Hence a fixture is a positioning or locating device whose function is to set rapidly and to hold securely for machining, a long succession of like details, with the least possible labour. Thus the process of marking out a job is dispensed with and much time is saved. The subject of jigs and fixtures in relation to drilling is dealt with at considerable length in Section XV at page 47 and more generally in Section XIX.

Like the pattern shop attached to a foundry the tool room attached to a machine shop is more a necessary auxiliary to production than a production department itself. It is self-contained, having its own equipment of light tools, as detailed in Section XIX, which can be run independently of the main machine shop.

Other Machine Tools. Planing machines (see Section XIII) are required for producing long flat surfaces, both horizontal and vertical, while "shaping machines" are useful for making short flat surfaces. "Slotting machines" (see Section XVI) are handy for forming vertical surfaces partly flat and partly round, and also for cutting keyways in wheels, though a special "key seating machine" is more efficient on the latter duty.

"Milling machines" (see Section XIV) can produce either plane or irregular contours with equal facility. They do more quickly much work that was formerly done on shaping machines. "Gear cutters" (see Section XXVI) in great variety employ the principle of both the miller and the shaper.

"Precision grinding machines" (see Section XVIII) are utilized for accurately finishing either cylindrical or flat surfaces. Though the practice of accurate grinding is relatively recent, its development has been rapid and it now occupies a place of great importance as a finishing process. "Screw-thread grinders" are particularly ingenious machines.

In the tool room (see Section XIX) "tool grinders" are used for sharpening cutting tools and milling cutters, while special grinders are made for sharpening twist drills. In the erecting shop, light "portable pneumatic and electric grinding wheels" partly replace the file for hand operations in trimming castings and fabricated details.

THE ERECTING SHOP

Apart from the test shop in an engine works the erecting shop is the final department of a general engineering works, where the finished details are put together or assembled to form complete machines. It is also the most interesting part of the works to most young engineers, who generally prefer fitting and erecting to either moulding or running a machine, as affording better opportunities for learning and advancement. Guidance on the fitting and erection of steam engines is given in Volume VIII at pages 8–24.

Fitting up general work at the bench, however, is a very different affair from putting together the various parts of a motor car on an assembly conveyor in mass production shops, which is far less attractive work to the majority of young men, though the pay may be good.

In certain classes of engineering work (such as the construction of conveyors and elevators), a complete plant is seldom erected and run in the shops, but usually on the site where it will remain. This may be either under cover in a comfortable factory or in the open air in an exposed position, where the erectors must suffer a certain amount of discomfort and possibly danger, especially in bad weather. Scaffolding, derricks, pulley-blocks, winches, and other erection tackle are required in addition to many hand tools and portable appliances. The final coat of paint has also to be given to the work after erection on the site and starting up.

Some helpful remarks regarding the duties of outside erectors engaged in the erection of steam engines on the site are given at page 25 and again at page 33 of the same volume. The ideal erector is something more than a good workman. It is not every man who does well in the shops that shines as an outside erector. His personality and temperament may be against him in strange surroundings. It is not sufficient for him to be a skilful workman. A leading erector must be handy with pencil and pen as well as with the hammer, file, and other tools. He should also possess initiative and be able to use his brains promptly in an emergency.

The subject of the fitting and assembly of the details of internal combustion engines manufactured in quantities is fully treated in Sections XXXI and XXXII, where not only new work but also overhauls and repairs to old engines are considered. Section XXXI is of special interest to motor car mechanics in garages.

Gas engines are as a rule bigger and heavier than petrol engines, less frequently produced in quantities and often made to order. Moreover, they are secured to fixed foundations instead of to a motor car frame, so that lightness is not so important and a flywheel of liberal weight can be fitted. In Section XXXII special attention is given to the fitting of step bearings and the important matter of lubrication by various methods as well as to the operation of valves.

The question of *foundations* deserves much study, not only for gas engines but in respect of all heavy machinery, especially fixed jib cranes, where considerations of stability under dynamic loads arise to complicate matters. Some information on the subject of foundations for reciprocating steam engines will be found in Section XXXIII on page 28, while the subject of ferro-concrete foundations for steam turbines is developed at some length in Section XXXIV (page 83) on turbine fitting and erecting.

Long-stroke slow-speed engines do not enjoy the popularity they did fifty years ago, before the advent of quick-revolution enclosed engines and their modern rivals, steam turbines and electric motors. Much information regarding the fitting and erection of the Belliss type of enclosed engine is given at page 40 in Section XXXIII, while steam turbines have a special section to themselves (Section XXXIV). A lot of auxiliary plant is associated with steam turbines, including surface condensers and pumps, pipe work, and valves.

Pump fitting is dealt with at page 58 in the steam engine section. Although many pumps of reciprocating types are still made, they have ceased to be of primary importance since multi-impeller centrifugal pumps (see page 70) were developed and perfected. The latter are now utilized for feeding high-pressure steam boilers and even for charging hydraulic accumulators, a surprising development! Thus pumping practice has been revolutionized during the present century. Centrifugal pumps lend themselves conveniently to direct motor driving through flexible couplings, without the aid of gearing, and are relatively compact, light, and quiet in operation. Before delivery to the customer pumps should be properly tested for capacity, head, and efficiency.

TESTING

After a machine has been constructed it has to be put through a running-in period, often followed by a series of trials or tests made to prove its suitability and adequacy for the duty intended, before being taken over. This is true of machinery generally, but heat engines in particular have to be tested for fuel consumption at various speeds and powers. There are also "endurance" trials, which are made only occasionally.

The testing of internal combustion engines and of steam engines is dealt with at considerable length in the concluding volume of this work. Such testing is a supplementary process to construction, made to satisfy the requirements of an engineer's specification, though it is not always insisted upon with machines of every class.

The testing of engines involves the intelligent use of numerous measuring appliances. Besides a reliable time keeper and a barometer, these include instruments for measuring varying volumes and weights, speeds and pressures, loads and torques, and temperatures both high and low. This means the provision of at least special calibrated tanks and thermometers, meters, tachometers and revolution counters, indicators, pressure gauges, brakes, and a stop-watch. A planimeter (see page 235 of Volume VIII) is required for measuring the areas of indicator diagrams, and also various scales.

Printed standard forms are employed for recording observations, and squared paper is useful for plotting the results of tests.

The construction and application of various types of fluid pressure indicators is an interesting study which receives attention at pages 166 and 205. Space has not permitted the introduction of a few indicator diagrams from internal combustion engines, showing the cycle of operations within the cylinder and the work done during a cycle; but an example of a steam engine diagram is shown on page 227. Much information can be learnt from a careful comparison of the shapes of such diagrams.

Having found the mean fluid pressure from the indicator diagram the calculation of the "indicated" horse-power is a simple matter; but the determination of the "brake," or external, horse-power is of more value. The ratio of the latter to the former is the mechanical "efficiency" of the engine, its value being about 92 per cent. The value of the thermal efficiency of engines in relation to heat consumption is considered at page 245. This figure is about 20 per cent.

When a dynamo of known efficiency is coupled to an engine it is easy to find the electrical horse-power by reading the voltage and amperes of the current generated and dividing their product by the constant 746. Then the brake horse-power of the engine is the electrical horse-power divided by the efficiency of the dynamo. This matter is discussed on page 241. In the case of three-phase alternators, however, generating alternating current, an adjustment must be made according to the "power factor," which varies considerably.

Dynamometers. In testing the power developed by an engine a brake of some kind is essential, the simplest being the rope brake described on page 186, which is suitable for measuring small powers only. The most useful form of absorption brake, however, is the interesting hydraulic dynamometer known as the Froude brake, from the name of its inventor William Froude, who died in 1879. It was first utilized on naval and experimental engines, an early example having been applied some sixty years ago by Professor Osborne Reynolds to the triple-expansion experimental engine at the Owens College, Manchester, used for research work. The sectional drawing of a modern Froude brake shown on page 216 should be carefully studied.

The theory of the Froude hydraulic brake deserves some study, being similar to that of the hydraulic coupling, or fluid flywheel. In this absorption dynamometer a stream of water flows through it and absorbs the heat into which the mechanical energy is converted.

The power absorbed is governed by the size of the running wheel, or rotor, and by its rotational speed. But it is not directly proportional to these factors. Actually the power absorbed by a Froude dynamometer varies as the fifth power of the rotor's diameter and as the cube of its speed, thus—

$$P = D^5 \times R^3 \times \text{a numerical coefficient.}$$

Hence a comparatively small rotor running at a good speed will absorb a high power. The numerical value of the coefficient depends on the units of measurement selected and on the operating conditions. In the case of the fluid coupling a thin mineral oil is the working medium instead of water.

Another interesting type of absorption brake is the Sprague electric dynamometer, depicted on pages 189 and 194. In this form there is coupled to the engine shaft the armature of a dynamo, whose magnet frame, or casing, is mounted on knife edges and provided with a weighted lever arm, which measures the torque balanced against the magnetic drag. The current generated may pass to storage batteries or be otherwise utilized, rather than wasted in generating heat through resistances.

In the case of large marine engines it is usual to equip the propeller shaft with a transmission dynamometer, whose indications enable the power transmitted along the shaft to be calculated from the torque and the speed. Several types of "torsion meters" (mechanical, optical, and magnetic) have been employed from time to time.

MACHINERY BEARINGS

The important subject of shaft bearings for engines and other machines is treated at considerable length in Volume VII, one entire section being devoted to plain bearings, and another to ball and roller bearings. The latter become relatively more important year by year, though they were hardly used at all half a century ago. They still are more frequently adopted for the lighter than for the heaviest class of bearings, more on the score of expense, probably, than for technical reasons. Large ball and roller bearings are indeed very costly and are a specialist's job, whereas big step bearings are regularly produced in a general engineering works.

One of the earliest applications of ball and roller bearings was to take the thrust of the hook on the bottom blocks of heavy cranes, thus permitting easy rotation of the load slung from the hook. Taper rollers were adopted earlier than balls for this purpose. Timkin taper roller bearings are much used nowadays for both thrust and journal bearings.

Although roller bearings of the "split" type are somewhat unusual, yet it is occasionally possible to adopt with advantage split self-aligning Cooper roller bearings for such applications as carrying the top shaft of a heavy bucket elevator, thus enabling the caps to be removed for the inspection of the bearings without dismantling the entire elevator.

In cases where low cost of construction is a vital consideration the simplest type of plain bearing without steps is not to be despised. Formerly it was customary in conveyor work to use plain cast-iron bearings, four diameters long, to support the slow-running shafts of coal conveyors and elevators. They did good service, too, on this duty, even in dusty situations, when fitted with Stauffer grease lubricators. Nowadays, though, standard plummer-blocks are more commonly utilized, being cheaply produced in quantities and obtainable from stock for general use. Ring-oiling bearings, however, are better for carrying quicker-running shafts, but the oil-wells need to be frequently cleaned out if the atmosphere is dusty, otherwise the rings will soon cease to pick up the oil.

The surprising variety of materials employed for bearings is enumerated in Section XXIX. Numerous methods of lubrication are dealt with in this section, while the subject of oil-less bushes is one of special interest in relation to the rollers of conveying machinery, where oil lubrication is often impracticable.

In all bearings a vital consideration is ease of replacement and repair. Some practical instructions on the preparation and casting of white metal linings are given in the same section. In arranging oil grooves an important principle is that the oil should be led into the bearing at the point of least pressure.

Forced lubrication by means of oil pumps has long been customary in high-speed enclosed steam engines, and later in petrol and oil engines, for serving the crankshaft bearings and the reciprocating parts.

Michell Bearings. The most outstanding improvement that has ever been made in heavy thrust bearings is the Michell bearing, with swivelling pads, which has completely revolutionized the construction of thrust bearings for marine propeller shafts, by reason of its more scientific design and greater compactness than the old multiple-collar thrust bearing. The latter had perhaps a dozen or more lower-half horse-shoe rings for receiving the ahead thrust from the collars on the propeller shaft and a dozen upper-half rings for taking the astern thrust. The same principle has also been applied to journal bearings. Although the Michell bearing has been dealt with to some extent in Section XXIX, the subject is nevertheless worthy of some amplification.

The sizes made range from 2 in. up to 30 in. diameter of shaft. Fig. 4 depicts a small-size single-collar marine thrust block, comprising a cast-iron cover and a base containing an oil bath with a journal bearing at each end. Lubrication is effected by means of an oil scraper at the top, which receives the oil raised by the rotating shaft collar and deflects it so as to fall over the thrust pads and feed the shaft bearings. End leakage is prevented by oil deflectors fitted at the ends of the journal bearings, no glands or packings being needed.

There is one slipper unit (Fig. 5) on the ahead side of the collar and one similar unit on the astern side. Each of these thrust units has four gunmetal pads, faced

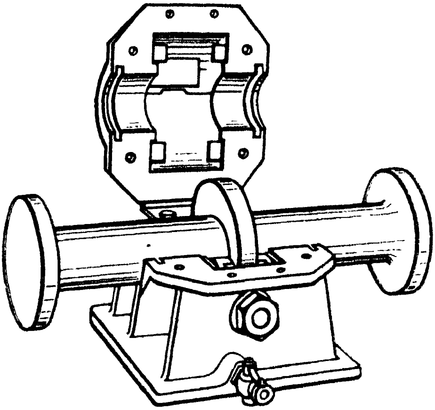


FIG. 4. "MICHELL" MARINE THRUST BLOCK

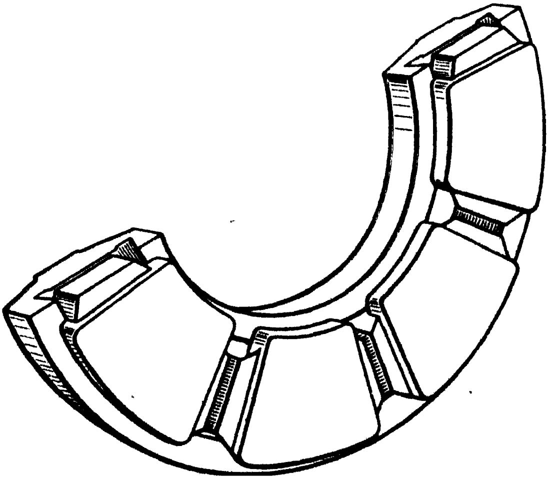
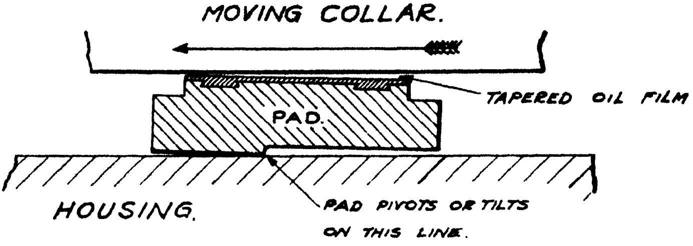


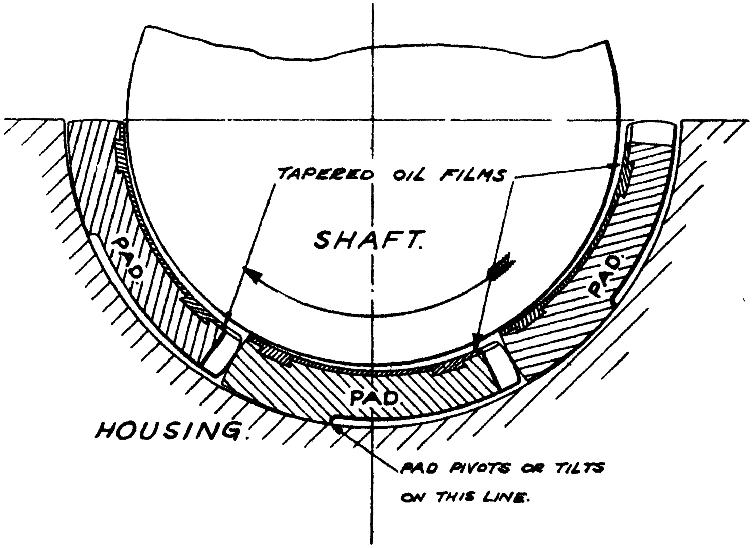
FIG. 5. SLIPPER UNIT FOR "MICHELL" THRUST BLOCK

with whitemetal, pivoting on radial lines at the back. They are mounted in a cast-iron frame or holder, the pads being so held that the combination can be handled as a single unit.

When studying the general principle of the Michell bearing one finds considerable help from the diagrams, Fig. 6, which indicate the action of a tilting pad, and Fig. 7, which illustrates the action of three pads in a journal bearing. These show the tapered oil film, or



THRUST PAD.



JOURNAL PAD.

FIGS. 6 AND 7. THE MICHELL BEARING

wedge of lubricant, that is self-generated by contact with the moving part without the aid of an oil pump.

These Michell blocks function without water-cooling at all usual speeds as given in the subjoined table, which also gives the thrust surfaces and the weights of a few sizes of blocks. Higher speeds than normal, however, demand a circulation of water, to permit of which a cooling coil is fitted in the base for coupling to a water service.

SPEEDS AND WEIGHTS OF S-TYPE BLOCKS

Diam. of Shaft	Speed	Thrust Surface	Weight of Block and Shaft
Inches	r.p.m.	sq. in.	cwt.
3	440	9·2	1·5
4	280	18·6	4·6
5	240	27·0	7·5
6	190	36·2	10·5

The diametral clearances range from 0·01 in. to 0·02 in. on the journal bearings, while the total axial clearance between the ahead and astern faces of the thrust pads is 0·15 in. normally.

For shaft diameters exceeding 7 in. a rather different type of Michell marine thrust block is widely adopted, but there is no difference in the principle of operation, and every size of block has only one collar, in striking contrast to the old multi-collar thrust bearing.

Amongst the merits of the Michell thrust block are—

(1) reduced frictional loss, the friction being only about one-twentieth that of a multi-collar block;

(2) no attention needed, beyond seeing that an ample supply of clean oil is kept in the bath;

(3) no adjustments are wanted, as there is no wear;

(4) economy of space and weight, and also in oil consumption;

(5) it will stand a big overload.

As regards *journal* bearings, it is recognized that a shaft revolving in an ordinary well-lubricated bearing with normal clearance forms a tapered oil film the thinnest part of which is just under the load. As the shaft turns, oil is drawn in to feed this wedge, and an internal oil pressure is set up in the film exactly balancing the bearing load. The faster the shaft revolves, the more oil is drawn in and the stronger the film becomes. Furthermore, the internal film pressure builds up to a maximum at the point where the load is greatest.

Actually, however, only about one-third of an ordinary journal "half-brass" or "step" is really effective, it having been found that a brass subtending an angle of 57½ degrees runs with only one-fourteenth the friction of a full half circle. Hence, if each superfluous side of the "step" can be cut out and replaced by a pad which can help to share the load, then the bearing will become far more efficient. This is what is done in the Michell journal bearing, as indicated in Fig. 7.

Thus the usual pair of solid "brasses" in an ordinary bearing gives place to six pads, each pad being free to tilt slightly in its housing. Oil is lifted up by a collar and guided into the oil annulus in the housing feeding the pads. Any surplus oil escapes at the ends of each pad, which creates its own oil film. Oil deflectors are fitted at the ends of the bearing.

Loads up to 5000 lb. per square inch of projected area are possible; and pads have shown no wear after ten years of service, because no metallic rubbing contact has occurred. Not only is the load-carrying capacity of Michell bearings enormous but the friction is far less than in the best plain bearing, so that they can safely be made much shorter.

It would appear that Michell journal bearings would prove very serviceable for the severely loaded bearings of calendering rolls and sugar cane crushers, provided a copious supply of clean lubricating oil could always be assured, as well as an atmosphere free from dust. It is doubtful, however, whether they would be equally suitable in places where the direction of the load constantly changes, as in the bearings supporting the crankshaft of a reciprocating steam engine.

Horizontal thrust bearings of the Michell type have been largely adopted for fast-running, high-duty centrifugal pumps, and also for fans and air compressors.

THE FRAMING OF MACHINERY

A study of the development of machinery frames or supports, quite apart from running gear, is full of interest and instruction. Timber framing came in first of all, as in engine beams, crane girders, and conveyor frames, and also in weaving looms and for storage bins. Wood is still occasionally used to a limited extent for framings, especially in places abroad where timber is cheap and readily available.

Next came the era of cast iron, which is still much employed for the frames of machine tools in cored sections and for textile machines in ribbed sections. But it has nearly gone out of use for the crab sides of cranes, for the troughs of conveyors, and for the casings of bucket elevators. Cast iron is a remarkably good material for sectional water tanks of large dimensions and for storage bins exposed to the weather, as it is not easily corroded. Moreover, flanged cast-iron plates can be conveniently bolted together to give any storage capacity required.

Then followed a period when wrought iron held the field for riveted girderwork, columns, crane jibs, hoppers, chutes, and so forth. This material also is relatively resistant to corrosion. In due time it was supplanted by the stronger mild steel, supplied in the form of plates, angle bars, channels, joists, and other rolled sections, as the prime material of construction for riveted and welded work. This includes not merely structural steelwork proper, but also hoppers, chutes, and the framing of some machine tools such as punching and shearing machines.

In the construction of fixed girders, columns, and storage bins there is at present a certain amount of rivalry between the two materials, mild steel alone in plates and sections on the one hand, and thin steel bars enclosed in a matrix of Portland cement concrete on the other hand, the latter being styled either "ferro-concrete" or "reinforced concrete." The building of ferro-concrete structures, however, is not included in engineering workshop practice, being carried out on the site by the aid of timber "shuttering" and portable concrete mixers.

Of recent years there have been big developments in the production or "fabrication" of welded steel machine frames and other parts, these supplanting both castings and riveted work. One may instance such parts as crane girders and crab sides, magnet yokes for direct-current motors, stator casings for large alternators, big steam condenser shells, as well as elevator casings, buckets, chutes, and bins.

In suitable cases greater strength is thus gained by less weight of material, and possibly greater reliability as compared with castings. Where only one or two large parts are wanted, there is considerable economy both in the time required for delivery and in the cost of construction, due to the fact that no patterns are necessary for use in the foundry. Moreover, alterations to parts can be made when needed without scrapping the work.

The case for "fabricated" structures and details is less favourable, however, when good quantities of running lines are wanted, where the cost of pattern-making for foundry requirements is relatively negligible.

One has to realize, too, that mild steel fabricated parts are more vulnerable to corrosion than are cast-iron parts and malleable iron details. Furthermore, it is not easy to test the soundness of a welded joint by any simple means other than its destruction, unlike riveted work. Much faith in the reliability of welding operators has to supplement visual inspection. As yet the microscopic and X-ray examination of materials is rather laboratory work than regular workshop practice.

Nevertheless both electric arc and oxy-acetylene welding processes are increasingly employed in modern engineering workshops. Oxy-acetylene cutting machines, too, are utilized for rapidly "cutting" or melting holes in steel plates by an intensely hot flame, no matter how thick the plates may be or how irregular in shape the required holes. For details of these processes and the plant employed the reader should refer to Section XXIII supplementing the practical Section XXVII on "Plate Shop Practice."

CONCLUSION

Before concluding this general survey of mechanical engineering as revealed by a tour through the shops and a consideration of the various sections of this multi-volume book, one must emphasize the fact that much of the success of a big manufacturing business depends on the efficiency of the arrangements for the transport of material and products within and between the different departments of the works; a matter involving the right use of trucks, cranes, conveyors and other lifting and moving appliances. This important subject is treated at considerable length in a special section of Volume VI entitled "The Mechanical Handling of Materials and Products."

SECTION II

HAND TOOLS AND GAUGES

BY

FRED HORNER

SECTION II

HAND TOOLS AND GAUGES

FROM a remote period in the history of man all cutting, scraping, and hammering has been done by hand tools. It is only quite recently in point of time that tools have been worked by machines, to afford that control which is absent in hand operation. Although machine tools for wood and metal working have developed with amazing rapidity during the past hundred years, there is still immense scope for the hand tools. Their use entails the application of a certain degree of skill and practice, but this is often restricted to just one or two sorts of tools, on mass production. The all-round workers are confined chiefly to carpentry and joinery and pattern-making, and in metal to the fitters and millwrights. It never pays a man to use a hand tool for any class of work of constantly-repeated nature (with certain exceptions), because machines are devised to produce so much more cheaply, and as a rule accurately, in a fraction of the time. But when shapes and sizes and contours are subject to continual variation, hand work fills a large place. It is not, however, possible to imitate the action of the lathe and some other machines by any kind of hand-cutting, with rare exceptions. Hand tools also deal with machine-cut articles for reasons of correction or finishing, although in big factories the majority of pieces are not touched by hand, except for gauging to ensure interchangeability. Repairs also involve the employment of all sorts of hand tools, with a good deal of skill in order to prevent the creation of errors, or spoiling of parts while being corrected and fitted.

GUIDANCE OF TOOLS

The essential in applying most of the cutting and scraping tools is that of accurate guidance, wholly or partly depending on the skill of the user. In a machine, guidance is taken charge of by the various elements—spindles, tables, slides—in such a manner that true contours are evolved, either straight or circular, or variously curved. In the case of the higher grades of machines, such as those for the precision grinding of metal pieces, an accuracy as close as $\frac{1}{10000}$th part of an inch can be guaranteed. Yet a skilled man with a simple scraper can gradually true a metal surface by the removal of minute quantities in spots indicated by a rubbing test against a master plate, so that truth of the highest known order in practical working can be attained. This, however, is a slow and somewhat expensive procedure, and is only applied to the production of true surface or test plates, and for slideways in good-class machines.

Guidance of a hand tool is often helped by the construction of the tool, notably in regard to the carpenter's planes, with sole sliding along the wood, or some of the saws with wide blades which afford a measure of control in the kerf. Drills, reamers, taps, and dies likewise guide themselves very efficiently after the start.

Yet many tools are controllable only by the skill of the hands, such as chisels for wood or metal, axes, files. The last-named are especially difficult to do true work with, because of the tendency of the hands to swing in arcs from the shoulder joints and file the work convex. The metal scraper previously mentioned has really no guidance at all, because it is tipped at an angle, and only the restraint of the hands decides how much is scraped off and where.

TYPES OF HAND TOOLS

The three main orders of tools are cutting (or scraping), percussive, and lever. The first is represented by such examples as the axes, adzes, chisels, gouges, planes, gravers, scrapers, files, drills, reamers, taps, dies, and saws as main types. The second by mallets, hammers, sets, punches, drifts, snaps, caulking tools. The third by crowbars, spanners, screwdrivers, pincers, pliers.

All the cutting and scraping tools are but wedges variously designed; they penetrate by a process of forcing the fibres apart, this being most obvious in the chisels for soft wood, and least so in metal scrapers. The first is a purely cutting process, the second scraping, with difficulty in removing even small quantities. The harder and tougher the material, as a rule, the less keen are the cutting angles, otherwise they would not endure. In point of classification the axe rather stands alone, because it is mostly used as a pure splitting or wedging-open tool, and its guidance is not good. The adze, on the other hand, has a single bevel instead of the double bevel of the axe, hence this, as with chisels, acts as a guide on the wood and enables fairly true surfaces to be cut with the exercise of a little skill. For trimming and truing heavy baulks and other pieces in carpentry and shipwright's work the adze is invaluable. The excellent guidance of the chisel by its flat face, Fig. 1, enables remarkably true cutting to be done for short distances, as also with the paring gouges. Chisels and gouges are distinguished by the terms, firmer and paring, the first-named being short and thick, the second long and thin. The bevelled edge paring chisels are preferred for nice work, being less obstructive to the view, and clearing in the cut better than the ordinary square edge ones. Many chisels and gouges are struck with the mallet instead of being thrust with the hands, and are preferably ferruled at the top end to prevent splitting. A socket instead of a tang fit of the shank and handle is also good for such purposes. Special narrow and strong chisels are used for mortising. The curves of gouges are made in great variety in sets from a very flat sweep to a very quick radius, Fig. 2 illustrating the extremes in each group. Carving tools occur in a greater range of shapes than the ordinary chisels and gouges, as they include straight and bent and cranked

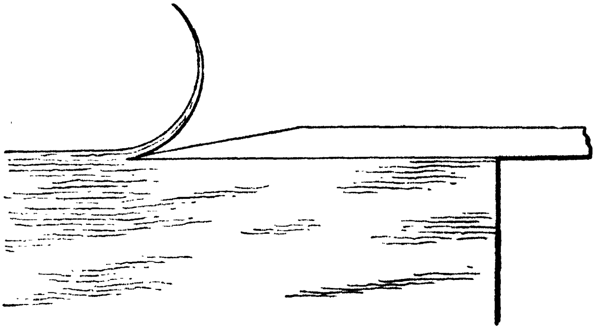


FIG. 1. THE PURE CUTTING ACTION OF THE CHISEL

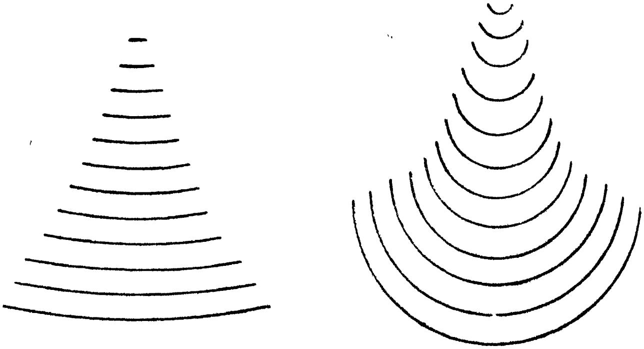


FIG. 2. THE EXTREMES IN CURVATURES OF GOUGES

chisel ends, and also "V" and gouge-shaped ends similarly set. The carpenter's draw-knife forms an intermediary between the chisels and the planes, being pulled by a handle at each end, for taking, if necessary, thick chips from the edges of boards, to lessen the labour of planing, and also for chamfering edges quickly.

The plane is in effect just a chisel in a holder, which compels it to follow a more or less true path, linear or curved, according to the shape of the sole. At one time the jack plane, its longer type the trying plane, and the short smoothing plane were the principal tools, together with a few special forms for grooving, etc. Now there is an immense choice in the way of iron and aluminium bodies, right up to the universal combination plane, taking about 100 different shapes of cutters as regular equipment. Most planes have single "irons," *A*, Fig. 3, but the jack, trying, and smoothing double irons *B*, which are stiffened up by the top iron, enable a finer shaving to be cut without tearing up the grain. A good example of a high-class plane appears in Fig. 4,

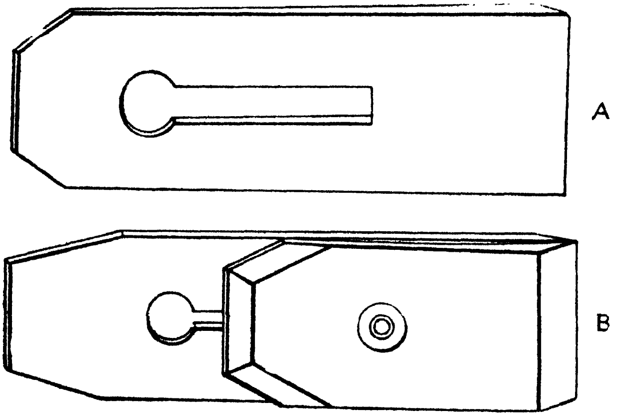


FIG. 3. SINGLE AND DOUBLE PLANE IRONS

the Stanley Bailey, shown with the iron taken out. The width of the mouth is regulated for fine or coarse work by means of the adjustable frog *A* ; this is held on its seating by two screws *B*. When loosened, the frog can be adjusted backwards or forwards by a screw *C* in the centre.

Small planes are made in many shapes for specific functions, as planing hollows and rounds, rebates, grooves, mouldings, dovetails. The circular planes are very handy, the sole being formed of a flexible steel plate, which can be adjusted to the desired curve for planing inside or outside radii. Unlike the draw-knife, the spokeshave has a face to control the depth of cut, and is therefore a species of plane, though the area of sole is not alone sufficient to ensure flat surfacing.

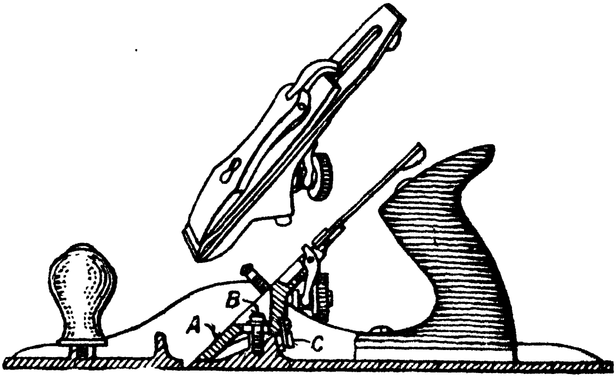


Fig. 4. A Good Example of an Iron Body Plane

COLD CHISELS

Although so many of the woodworking chisels and gouges are thrust by hand or malleted, the engineer's cold chisel can only be made to cut with a hammer (or its equivalent the pneumatic hammer), and there is little or no guidance, the results depending on the skill of the user. Cutting off can be done well enough with an indifferently-shaped and ground chisel, but good chipping is only possible with a nicely-shaped and ground tool. The end should be as thin as practicable without risk of fracture, both for good visibility of the operation and to facilitate re-grinding in the shortest time, Fig. 5. The edge must be ground with a slight camber, in order to prevent the corners from digging in and fracturing. It is neither necessary nor desirable to hold the chisel with a rigid grip, as this quickly tires the hand, and gives a tendency to shivering blows, the jarring of the edge against the metal being likely to crack the edge. A light, easy grip is sufficient, and the edge should be pushed up against the metal before

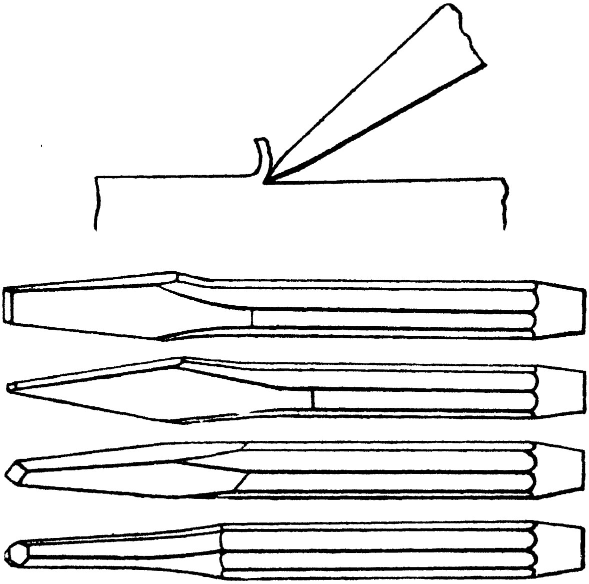


FIG. 5. THE ACTION OF THE CHIPPING CHISEL AND THE FOUR PRINCIPAL KINDS

striking each blow. In the old days of millwrighting and extensive hand surfacing the cold chisel was an important tool for dealing with quite broad areas and long guiding surfaces, but the invention of the planing machine altered these conditions. Whenever surfaces are trued with chisel and file it is customary to use the cross-cut chisel first and rough off the metal in a series of grooves or narrow cuts, followed by others at right angles, and then generally level the metal with the ordinary broad-nosed chisel, after which the file provides a further state of accuracy. The chief cases now where such work is done are those on out-of-door jobs requiring fitting or alterations, and breakdown or repair work in mills and factories and out of doors, for which no kind of portable machine tool is available. The other standard shapes, the diamond-point and the round-nose, are used for a variety of severing and grooving, the round-nose being bent for oil-grooving in bearings. The relative keenness of cutting angle depends on the class of metal or alloy to be chipped ; brass, gunmetal, and like easy materials are dealt with by a thin, keen-edged chisel without fear of fracturing it, cast iron by a rather stronger angle, and cast and wrought steel by a temper less hard, as the difficulty of penetrating these materials tends to shiver a hard edge.

The smith's setts are of the chisel class, being held by withy or wooden handles and struck with a hammer. Some cut hot metal and are ground with a very acute angle, and others cold, needing a stronger formation. The hardie is a type of sett stuck in a hole in the anvil, and the iron is laid on its edge and struck to cause partial severance ready for breaking off.

Gravers are a small species of chisel with a knob-ended handle of rather large diameter, for pushing and bumping with the hand ; they are variously ground with flat, diamond, and half-round cutting ends, and with straight or bent shanks. Their employment in engraving demands much skill and patience.

Scrapers are of two principal classes: those for woodworkers which consist of a simple plate of tempered steel of suitable contour, flat or curved around the edges, or held in a handle for convenient use; and the engineers' scrapers, which have plain shanks like those of files, and are handled similarly. The woodworking tools are used for neat finishing, the metal scrapers to obtain a high state of accuracy, excepting in those cases where they merely remove dirt, carbon, caked oil, etc. The method of scraping is to take off small particles in localized areas, so as to obtain an intimate fit of a matching part. The slideways of good-class steam engines, and those of lathes and many other machine tools are accurately finished by scraping. A standard surface plate (itself scraped very truly) is used for testing by the transfer of a thin film of red lead from its face to that of the piece of work. The "high" spots are thus indicated on the latter, and the scraper removes these carefully and makes another trial until a sufficient degree of truth is obtained. Towards the end of the process the red lead film must be very thin or absent, the bright contact spots showing the state of affairs. And at this stage great care is essential not to scrape too deeply at any one place, or the whole area may have to be gone over again to bring it down to the level of the reduction. The scraper is ground finely across the end, Fig. 6, and then oilstoned to eliminate totally the grinding scratches, with frequent recourse to the oilstone afterwards.

The scraping of cast iron, gunmetal, bronze, or white-metal bearings is a necessity in high-class construction, to ensure that a shaft or spindle shall make equable contact all over. If this is not so, and the touching only occurs in patches, the oil will be squeezed therefrom by the localized pressure and the bearing is likely to run hot and seize. But contact all over means that the shaft rests on an oil film, and never really makes metal-to metal contact. The procedure is that of taking frequent rubbings, smearing the journal thinly with red lead mixture, and rotating it a few times in the bearing. The high spots are thus indicated, and are scraped down carefully, using the bearing scraper shown in Fig. 6. If the brass has been bored or reamed well, and the bearing stands in alignment, it will not take long to obtain good fitting. The bare shaft will do near the final stages, showing brightened spots in the bearing.

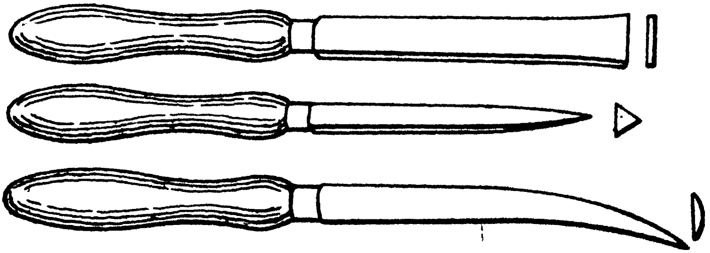


FIG. 6. METAL SCRAPERS FOR FLAT SURFACES AND FOR BEARINGS

FILES

These are invaluable tools for some kinds of woodworking and practically all metal working. They are made in an extensive range of sizes, shapes, cross sections, and with different sorts of teeth. Although it is not economical to do heavy filing if a machine or grinder will remove the metal, there are some kinds of heavy work which may have to be filed, such as on tramway construction, and in certain sorts of erection of machinery and structures, as well as on occasional breakdown work. A few workshops also use heavy files, but in the majority of cases they have been replaced by grinding machines. When manufacturing is done on the interchangeable plan there may be no use at all for either files or scrapers, or only a limited scope to finish certain small parts to gauge. The most highly-skilled filing is that performed by the locksmiths and gunsmiths, and the die-sinkers.

Files are either single-cut (or float-cut) or double-cut, the latter with a second set of chisel cuts crossing the first. In single-cut files the various degrees of coarseness are dead-smooth, smooth, second-cut, bastard, middle, and rough; in double-cut they are dead-smooth, smooth, second-cut, bastard, middle, and rough. Rasps used chiefly by woodworkers and farriers are made in six degrees, the coarsest being the horse rasp. Sand-blasted files are those in which a stream of sand and water has been directed by a steam jet against the backs of the teeth. This grinds off the burr thrown up in the cutting, and leaves each tooth a keen well-supported edge, Fig. 7. Worn files are also sharpened up by the sand blast.

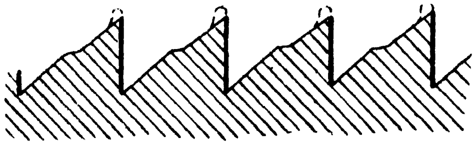


FIG. 7. FILE TEETH SHARPENED BY SAND BLAST, WHICH REMOVES THE BURRS (DOTTED) LEFT FROM CUTTING

The dead-smooth files have extremely fine teeth (as many as 120 to the inch) and are only employed for the finest finishing, including that in the lathe. Using them on rough surfaces rips out the delicate teeth. The smooth file is not so liable to be damaged, and is utilized extensively for finishing, while the second-cut is the most generally useful tool for all-round work, but the bastard, middle, and rough are necessary when any amount of metal has to be removed preparatory to finishing.

Before explaining the methods of using files, brief mention may be made of the longitudinal and cross-section shapes, as they affect the class of filing done. The flat types of files are varied in the relation of thickness to width, the thinnest being the warding files used by machinists, jewellers, and locksmiths to file the ward notches in keys. As a class by themselves the watchmaker's and jeweller's needle files are the finest sorts of any made. When filing has to be done against a ledge or shoulder without altering it, the safe-edge file guarantees this, one edge being ground smoothly. The files of oblong cross-section are furnished both in tapered and parallel lengths, as are likewise the square, triangular, round, and half-round. Many special forms of files are sold for sharpening different kinds of saw teeth, and certain machine knives, while the rifflers have double ends of curved form to reach into situations not accessible to a straight file. Most files are single-handed, but the rail files are often fitted with two handles, for two men to exert the necessary pressure and power. The shape of handle is not of much importance in fine files, a parallel one being handy and comfortable to grip with the fingers. But for the heavier thrusting it is essential to guard against fatigue of the hand, which can be ensured by using a handle with knob end of generous curve (as distinct from a pointed end) so that the pressure is distributed over the palm.

THE ART OF FILING

This comprises the best choice of files and their proper manipulation. A new file is somewhat delicate on the teeth, and the pressure should be lightened accordingly to avoid snapping many of them off. It is best, if the nature of one's work allows, to start all new files on brass or gunmetal or bronze, and not put them to iron or steel until later. They will cut the latter readily when too worn to file brass efficiently. A good file should never be used on scale of a casting or forging, nor on a hard weld. Another bad practice is that of striking up against a sharp edge *A*, Fig. 8, which breaks the teeth easily; rather should the inclination lie as at *B*. In a like manner the filing across of very narrow edges does damage to a good file, because of the few teeth in action at a time. Any pressure on the backward stroke of a file is unnecessary and always harmful.

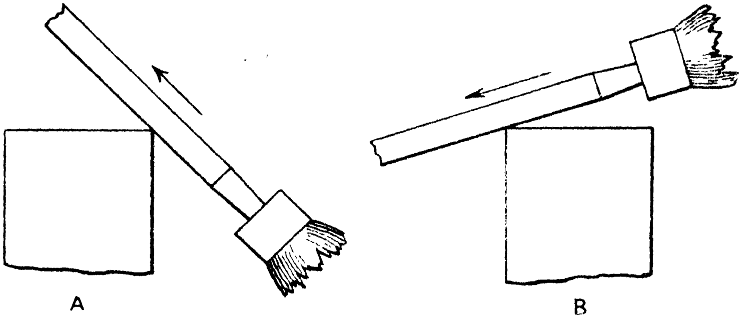


FIG. 8. INCORRECT (*A*) AND CORRECT (*B*) METHODS OF APPLYING FILE ON CORNERS

In order to remove metal in the fastest time and with the minimum of effort, the method of crossing strokes should be pursued in all cases where practicable. First the file is swept diagonally as in full lines in Fig. 9, and then after a while in the other direction as shown by the dotted lines. The second action has the result of topping off the ridges left from the first strokes, it always being easier to file off these than solid continuous metal. These alternate diagonal positions are continued until the surface is ready for the finishing. Metal may be roughed quickly with the backs of half-round and corners of square files. Beginners always find it impossible to file flat, but this fault can be gradually corrected by practice. The forward end of the file tends to rise and the handle to drop, so if these tendencies are consciously resisted at first by a downward control of the one end and a lift of the other the filer will soon acquire a natural and unconscious habit of filing flat. Long narrow surfaces are largely finished by draw-filing, which is comparatively easy for a beginner even to pursue ; the tool is grasped by the hands on each side close to the work and rubbed to and fro with a steady motion, Fig. 10. Another way of getting a true face on blocks of small size is that of laying the file on the bench and rubbing the work on it. When filing work rotating in the lathe it is not necessary to move the file much excepting in slow strokes, with a slight lateral motion, so as to avoid the formation of circular scratches.

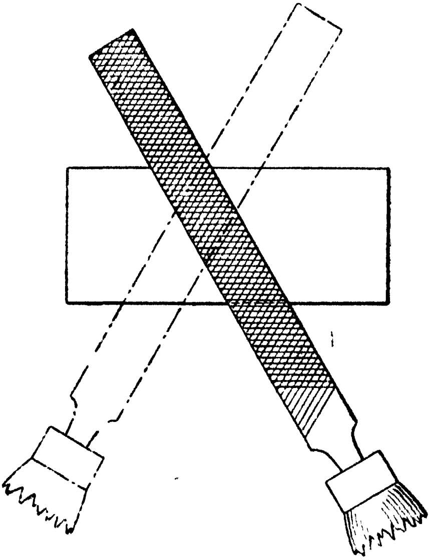


Fig. 9. Alternate Directions of Filing to Rough-off Metal Rapidly

Pinning or the choking of the teeth with filings is troublesome in dealing with certain materials. A wire brush is necessary frequently to clear the spaces, or if the bits are stuck hard they must be picked out with a piece of pointed wire. Chalk rubbed on to a smooth or dead-smooth file largely prevents pinning, as does the application of oil. The latter stops the tool from cutting so freely, but this is often an advantage than otherwise for fine work. Large surfaces cannot be readily filed because of the interference of the handle, hence the tang must either be cranked up to keep it off the metal, or the tang must be held with a " surface holder," which grips it and also presses on the top of the file near the point.

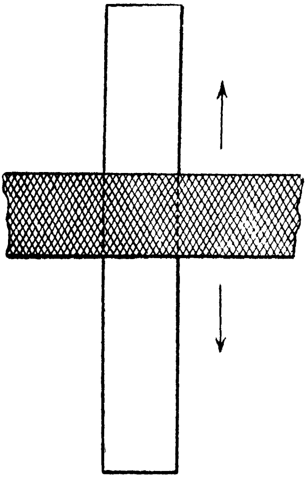


FIG. 10. DRAW-FILING, TO OBTAIN FLATNESS ON NARROW SURFACES

SAWS

These are remarkable for the great variety of shape and sizes of the blades, while there are a number of different forms of teeth for various reasons. The wood-cutting saws are tempered soft by contrast to the hack saws for iron and steel, but the second-named cannot be sharpened by filing, the grinding wheel being the only method, and this is done in some of the more expensive blades. Some teeth cut only on the forward stroke, some on both strokes. The sizes of teeth are

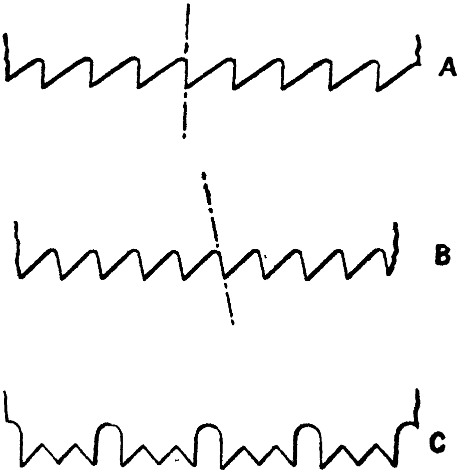


FIG. 11. TYPES OF SAW TEETH

A = Saw teeth for ripping
B = Teeth for cross-cutting
C = Farmer's tooth, for rough sawing

expressed in "points per inch," counting the extreme points at each end. Saws for wood have teeth of shapes and angles determined by the relative hardness or softness of the timber, and whether ripping or cross-cutting is to be done. Teeth are pitched more finely for cross-cutting than for ripping. The rake or angle of the front of the tooth affects the cutting powers. In the common hand saw for ripping the front of the tooth lies at a right angle with the line of teeth, Fig. 11, *A*, but for cross-cutting a negative rake *B* is given. Negative rake has the effect of lessening the tendency of the tooth to catch in, though, on the other hand, it cuts less rapidly than one with more rake. Many of the larger cross-cut saws are made with "V" teeth of equal slope on each side of the point, and cut on the to-and-fro stroke equally well, or "M"-shaped teeth are utilized, also called the farmer's tooth *C*, being suited for a rough class of cross-cutting. A few "peg" teeth of fine pitch are often cut at the end of a big cross-cut saw (or at each end for a two-man saw), with a view to assisting an easy start to the main teeth. Large saws are frequently formed with more complicated teeth than the "M," "cleaner" teeth being interspaced so as to plane out the kerf and clear it of sawdust quickly. The truth of cutting with a wood saw depends not merely on effective guidance by the user, but on the truth of the blade, its temper, and the set and sharpness of the teeth. Uneven set causes the teeth to wander to one side, while a blade that is untrue, or not tempered nicely, will also cause straying. Gripping the saw hard and keeping one's arm rigid are unnecessary, and not likely to produce an accurate cut. The small back or tenon saws are so thin in the blades that they need artificial stiffening through the medium of the iron or brass back, and this must be attached efficiently and in such a manner that it will not become loose, otherwise the blade will buckle.

The saws for metal are practically confined to the hack-saws, with the slight exception of piercing saws (like fret-saws) for sheets, and small back-saws for cutting off brass rods and tubes, etc. Differences in hack-saw teeth are those of number per inch, sixteen or eighteen being suitable for general use. For cast iron or mild steel a fewer number per inch is often adopted, but for cutting tool steel, brass tubing, and sheets finer pitch becomes essential to avoid fracture and catching-in. The finest pitch is thirty-two per inch. Flexible-back blades are hard only at the teeth instead of throughout the blade, as in ordinary practice ; they are more suited for certain difficult sawing in which catching and twisting are likely to occur, such as pipes, angles, tees, channels, and other awkward sections.

Precautions in using hack-saws are firstly to strain the blade up tight in the frame, and secondly to grip the latter comfortably, without bending the blade sideways. As with files, it is preferable to use a new blade on soft stuff, such as brass, until the teeth have become slightly dulled, also the pressure on the frame must be moderated with keen new teeth, or they are liable to snap off. Starting in an upward direction against an edge is not right, the principle being the same as for files, Fig. 8. Very rapid reciprocations do no good, as the teeth skid across without penetrating properly ; a steady fifty strokes to the minute is quite sufficient. A good blade should not be applied to the kerf left from a more worn one, because the keen corners of the teeth catch in and break off. If for any reason (such as a broken blade) a cut cannot be completed with a worn saw, the safest plan is to turn the work over and start as accurately as possible on the opposite side, taking great care as the new teeth reach the old cut. A good practice, if much sawing of a varied character has to be done, is to keep two frames in service, one with new blade for brass, etc., the other a more worn one for iron ; or one ordinary pitch blade and one fine. This saves time and economizes in saws.

TOOLS FOR MAKING HOLES

There is a considerable difference in the use of boring and drilling tools in machines and those worked by hand. In the first case the control of the tool is exact, and it penetrates at the angle desired, and does not stray (unusual circumstances excepted) in passing through the material. Neither is there any difficulty in getting a start in the wood or metal or other substance, and the feed mechanism ensures a steady travel at regular rate until the required depth has been reached. But the hand-manipulated tools, those for wood in particular, are not easy to start in or keep feeding without some special provision at the point. They are liable to deviate (especially when knots or grain interfere with the passage of the entering end), and a smooth, round, and straight hole is not easy to make because of the tendency of the cutting edges to tear up the grain. End grain presents more difficulty than cross grain to some kinds of boring tools, and soft wood is often a different proposition from hard—that is, the same tools will not always operate efficiently in both. Drilling in metal is really more simple, because the same sort of drill will work in any metal or alloy, and the guidance is fairly well assured, with the exception of chance deflection from the presence of blowholes, or flaws, or seams in the metal. Thin sheets are difficult to drill truly, because the point of the tool emerges before the full diameter has been drilled, and there are special drills to suit this class of work. A simple method, however, for occasional operations is to clamp the sheet on a block of scrap metal and let this receive the point.

WOOD-BORING TOOLS

Large numbers of small holes made in wood do not demand anything particular in the way of accuracy, as when a screw or nail or brad requires some preparatory entrance made. The bradawl and the gimlet are quick-acting tools for these requirements ; the former acts by a thrusting aside of the fibres, but the gimlet is more of a cutting tool. In the shell type the cutting begins at the entrance of the shell, and of the twist in the twist gimlets; each has a taper screw point to worm the tool in and help it to keep straight. The shell tool becomes choked with the cuttings more than the twist, although in hard wood either soon becomes choked, and must be withdrawn frequently for cleaning. The shell, spoon, and nose bits of approximately half-round cross-section possess moderately good guidance, but the chip-clearing capacity of the first two is moderate, while that of the third is much better, because the nose, Fig. 12, brings out the core on the withdrawal. The long carpenter's and ship augers are formed similarly and worked by a cross-handle.

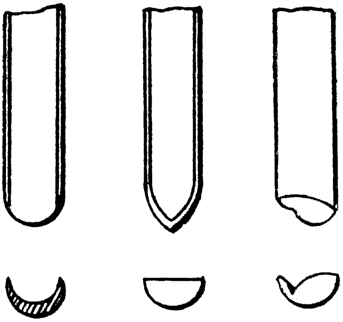


FIG. 12. SHELL, SPOON, AND NOSE BITS

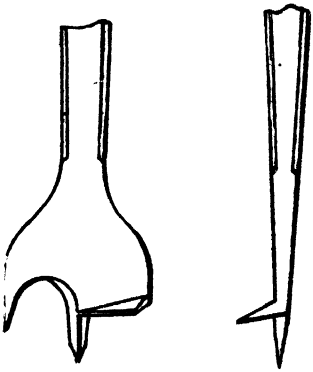


FIG. 13. CENTRE BIT WITH NICKER AND CUTTER

More accurate boring can be performed with certain tools that possess nickers, or knife edges which cut a true circle and clear the hole while the end cutting edges remove the wood. The centre bit is an example suitable for moderate depths, although its guidance cannot be good for any extended distance. Some have a screw point to help draw in, and expansive bits are also supplied, with adjustable cutter to bore to different diameters. The screw or spiral augers and auger bits are a faster cutting and more accurate class of tool, also suited for deep boring. They are usually balanced in action, from possessing two cutting lips and two nickers, preceded by a taper screw starter. and the body. with its spiral formation, affords both guidance and power to propel the cuttings out of the hole. In Fig. 14, the Jennings, *A*, has the nickers projected forward, the Gedge, *B*, has curled lips, while what is called the solid nose or unbreakable, *C*, is formed with a continuous web at the lips. The Irwin, *D*, differs from all other double-twist bits in having a single spiral, forged with a cylindrical shank ; this gives great stiffness, and the

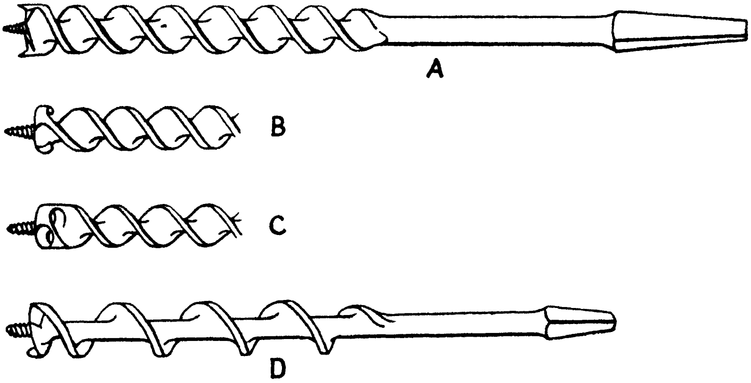


Fig. 14. Types of Auger Bits

A = Jennings. *B* = Gedge. *C* = Solid nose. *D* = Irwin cuttings have plenty of space to work out of the hole. A special type is the Forstner bit, which has a circular rim and no centre screw ; the rim affords excellent control and suits the tool for high-class boring and recessing. The hollow auger cuts parallel or tapered pins, dowells, tenons, or ends of spokes. It is driven by a brace, and the cutters are either fixed for one size or are adjustable. Tapered holes are bored by a bit of half-round cross-section suitably tapered, and countersinks either by a " snail " or two-lipped end, or by a rose countersink, having a number of teeth.

DRILLS FOR METAL

The drilling of holes in metal by hand-operated drills is usually a thing to be avoided if it is at all possible to do them in the lathe or drilling machine, or with a pneumatic or electric drill. Excepting in the case of small holes through thin or soft material the labour of drilling is considerable, although quite large holes can be put through steel at a slow rate with the ratchet drills when other methods cannot be applied. Other hand drills include the ordinary cranked brace and the geared drill, very small holes being dealt with by the Archimedean and the bow or fiddle drills. It is important to have the drills perfectly formed and kept sharp and the points should end thinly, otherwise there will be wasted labour in grinding thick points round and round at the bottom of each hole. Speed is essential for quick working, though it is not attainable in hand machines to the extent that a power-driven drill provides.

The older type of flat two-lipped drill still finds much favour in small sizes, being made with equally bevelled lips for the fine drills, so as to cut in each direction when rotated to and fro by a bow drill—the watch and clockmaker's tool—but in all other cases cutting only on the one direction of rotation, usually right-handed. This difference affects the capacity of the cutting, for in the double-acting drills the edge has negative rake, causing it to scrape with more or less difficulty, while in the single-acting type the shape approximates more to a true cutting action, a necessity in drilling iron and steel, though not quite so important in regard to brass and other soft stuff. The curving forward of the lips is sometimes done so as to impart front rake and fit the tool for penetrating wrought iron and mild steel, but generally the front face is flat, *A*, Fig. 15. Or a groove may be ground, *B*, to obtain the same result, though this is soon lost on a few sharpenings. The actual point does no sort of cutting, and should therefore be as narrow as

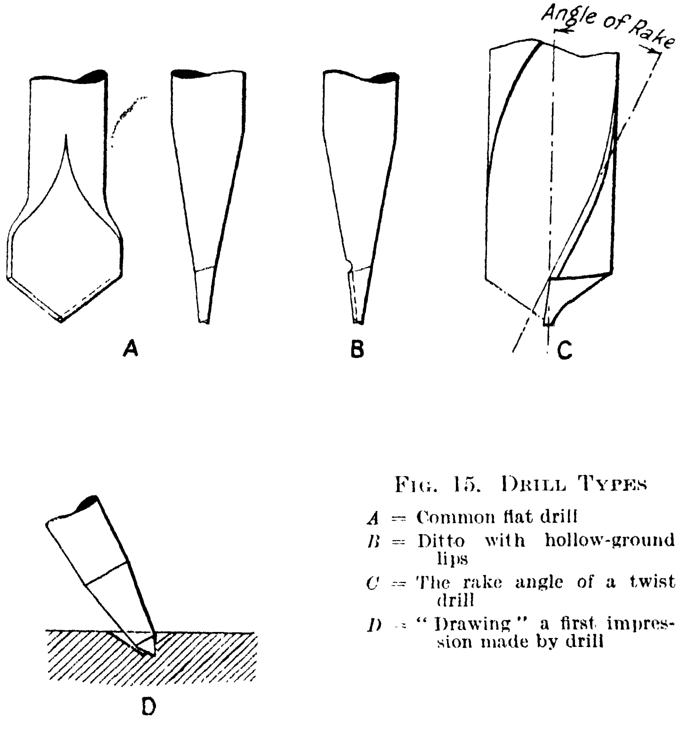


FIG. 15. DRILL TYPES

A = Common flat drill
B = Ditto with hollow-ground lips
C = The rake angle of a twist drill
D = "Drawing" a first impression made by drill

possible, consistently with ability to resist splitting. The twist drills are superior to the flat ones for three reasons: (1) the twist has the result of giving top rake to the lips *C*; (2) the spiral assists in worming the chips out of the hole; and (3) the body affords good guidance in the hole to keep it straight. The only objection to the drill is that on breaking through the metal at the back it tends to screw rapidly through, with possible breakage. This is more readily checked in a machine than with any hand brace. As the tendency is more marked in brass, gunmetal, bronze, etc., a straight-flute drill is usually employed for these, the cross-sectional shape being much the same as that of the twist drill.

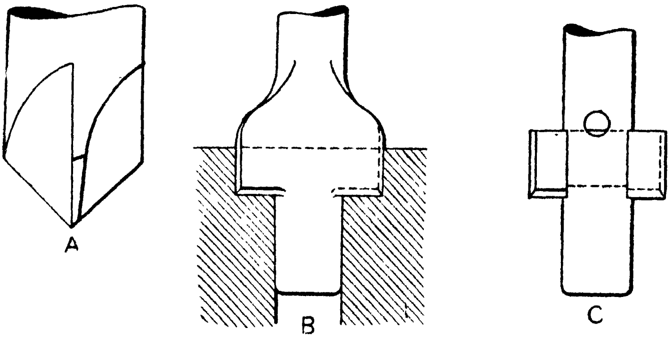


FIG. 16. COUNTERSINKS AND COUNTERBORES

A = Four-lipped countersink
B = Solid counterbore
C = Counterbore or facing cutter held by wedge pin

The starting point for drilling is usually that of a centre-pop struck on the metal, and with care there is no difficulty in drilling accurately thereto. But the drill often tends to wander to one side, and if the position is important, it is safer to strike a circle with the compasses, and observe the concentricity of the recess after a few turns of the drill. If out of centre, the impression can be "drawn" by striking with a centre punch or a chisel *D*, so as to leave a cavity into which the drill point will slip, and so lead the recess over that way. The drawing should be done at an early stage, and repeated if necessary because, when the recess has nearly reached its full diameter, correction becomes difficult. Brass and similar alloys are readily drilled without the use of a lubricant, also cast iron, but wrought iron, malleable cast iron, and steel require soapy water or oil to cool and lubricate the drill.

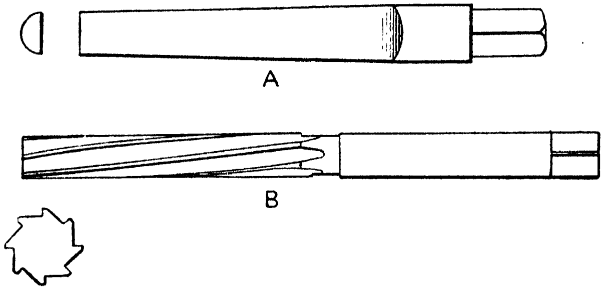


Fig. 17. Typical Reamers

A = Simple reamer of half-round section
B = Spiral-fluted reamer and shape of teeth viewed from end

Exceptionally hard steel must have paraffin or turpentine, the latter also being applied for glass.

Countersinking and counterboring require a different species of tool, the second-named demanding guidance to keep the recess concentric with the hole. Countersinking may be done with an ordinary flat drill, if of suitable angle to suit the screw or rivet head, but the recess does not always turn out smoothly. If this is necessary a countersink with more than two lips is steadier and does not jump and chatter ; *A*, Fig. 16, shows one with four lips. A counterbore is provided with a guide pin which fits in the drilled hole, as in the solid style *B*, or is made with an interchangeable cutter for different diameters of recess *C*, a similar tool with cutter of suitable diameter being used for facing a boss to take a head or collar.

Reamers are essential to finish straight and true holes which are not sufficiently accurate when drilled, or do not lie quite in line in two or more pieces of metal joined together. Tapered holes must also be reamed, after rough drilling. The clockmaker's broach is an old form of tool for taper work, but it does not cut very freely because of the obtuseness of the edges. A half-round section is fairly efficient, and can be readily made from a piece of silver steel, Fig. 17, *A*, but the regular fluted reamer is the best class for cutting, *B*. Pipe reamers are of steep taper, and used to take the burr from iron, gas, and steam pipes after cutting off ; there is one for the mouth of the tube, and a hollow one for the exterior. Taper reamers are furnished to suit the purpose required such as to match standard taper pins or the Morse tapers employed in lathe and drilling machine practice.

SCREWING TACKLE

There is but a moderate amount of screw-cutting done on wood, and for this iron taps are used, and the screw-box with a cutter inserted, the range extending from about ½ in. to 3 in. diameter. But for metal working a much more elaborate range occurs, comprising different designs and classes of taps for the various standard threads and screw plates, stocks with sliding dies, circular dies of solid or adjustable type, die nuts, together with numerous handles and stocks for operating these tools. All are self-feeding after a fair start has been made, but do not necessarily follow a true linear path, that is, one may tap a hole out of square or get a drunken thread with a die. The start is, however, the main thing ; in the case of taps a certain length of plain, parallel, or slightly tapered portion leads up gradually to the threads, and in dies similarly. The latter, however, are able to finish a thread completely, but first, second, and third taps are required to complete a thread to the bottom of a blind hole, the third or bottoming tap having full threads all along its cutting portion.

Sighting enables one to judge whether a tap is keeping upright in the hole, or a steel square can be applied against the tap to ascertain the relationship with the face of the work. A tap guide is sometimes used in particular work; this has a foot that is attached to the face by a screw or a clamp, and the hole at the top encircles the shank and compels it to stay vertical, Fig. 18. Another method of obtaining perfect truth is to perform the operation in the lathe. The piece being gripped in the chuck, the hole is drilled by a drill fed up from the poppet. Then the tap is inserted, prevented from rotating by a wrench, and the belt pulled on to revolve the work. Meanwhile the back centre is kept constantly up to the countersink in the top end of the tap, which cannot therefore get out of alignment. Or in some instances the tap can be turned

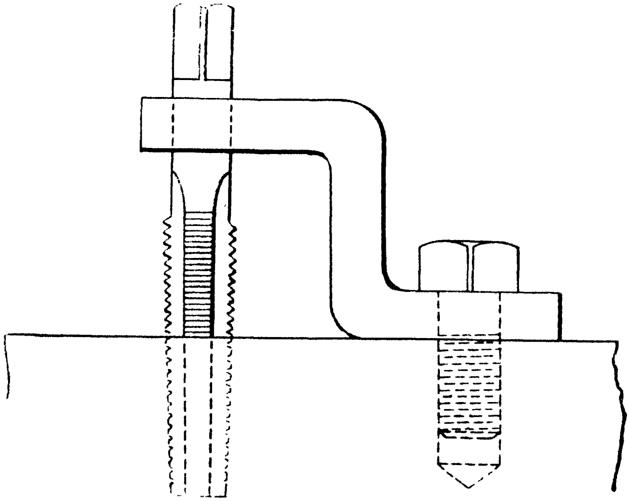


FIG. 18. TAP GUIDE, USED WHEN HOLES MUST BE TAPPED SQUARE WITH FACE OF WORK

with the chuck, and the article rest against and be fed up with the poppet drilling pad. And there are, of course, the drilling machines available for working taps, or for regular production, the tapping machines.

Taps and dies are subject to rather strenuous duty, and must be made of high-quality steel, accurately tempered, and kept sharp. They must never be applied on sandy or scaly surfaces, such as cored holes or forgings or black rod, or to clean out case-hardened threads. Actually in engineering work black punched nuts are threaded with long taps, and black rod threaded, each under a copious flood of lubricant. But it is not advisable for the ordinary hand user to attempt such things and expect the tools to remain in the condition required for fine work. Taps are easy to break, though the best are tempered softer in the centre, leaving a tough core. It is a danger sign when the wrench springs round slightly without moving the tap, and shows that the hole has been drilled too small, or that more lubricant is wanted, or that the tap needs sharpening. A partial backward turn after some amount of forward progression eases the tap, a like idea being judicious with dies.

All the early taps were provided with either three or four flats, the same practice being sometimes followed by amateurs who make their own ; as evident from the cross-sectional shapes sketched in Fig. 19, *A* and *B*, there can be no proper cutting action, but only a part squeezing, part scraping removal of the metal. If, however, a curve is made to give a semblance of front rake, matters are much improved. Two-flute taps are formed in this way for tapping soft, tough steel and brass and aluminium, the flute area affording plenty of space for the flow of chips. Three flutes are also good for the same reason. The relief of a tap, that is, the reduction in diameter of the threaded portion for a certain distance, in order to prevent it rubbing all along the threads and going very hard in the hole, is mostly done by a gradual and progressive relief from the cutting edge towards the heel *C*, or, more recently, a "con-eccentric" relief *D*. This embodies a full diameter of thread for about one-third the way around the land, and then a falling away. The guidance in the hole is good, and the faces can be sharpened repeatedly and still the effective full size remain.

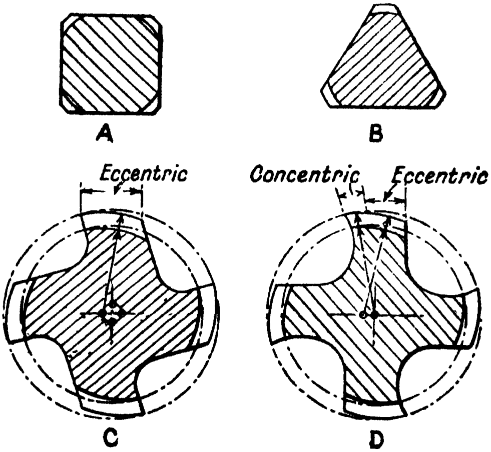


FIG. 19. TAP CHARACTERISTICS

A and *B* = Cross-sections of taps with flats filed or ground
C = Tap with milled flutes and eccentric relief to threads
D = Con-eccentric relief, which preserves the "size" a long while

A set of taps for hand working usually comprises three—taper or first, second, and plug or bottoming—but a large amount of machine tapping is effected with one tap only. If a hole is a thoroughfare one, and the first tap can be passed right through, there is no need to use the others; the point of this tap has a short parallel or reaming section, which ensures that it cannot be used in a hole too small, and also helps to start it truly. Serial taps in sets differ from standard hand taps in being made slightly smaller in diameter from the first to the third, so that each cuts a trifle larger, and the duty is divided in severe operations, as in tough steel likely to break ordinary taps. Recently, a modified class of tool, the spiral-pointed tap, has been developed for tough materials. The cutting edges, which remove practically all the material, are sloped in the direction seen in Fig. 21, and the faces are hooked so as to impart front rake. The chips come off in long curls and, instead of going up the flutes as usual, are passed out ahead. This means that shallow flutes are sufficient, and the tap may be made very strong in consequence.

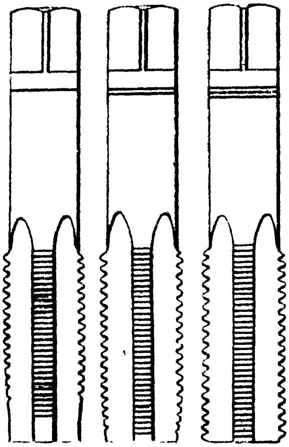


FIG. 20. FIRST, SECOND, AND THIRD TAPS FOR HAND-WORKING

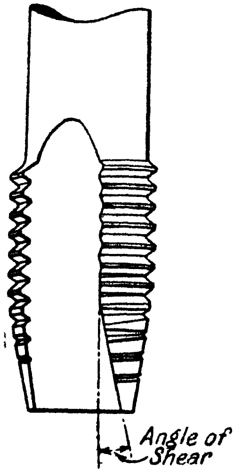


FIG. 21. SPIRAL OR SHEAR-POINT TAP, WHICH SENDS THE CUTTINGS OUT AHEAD INSTEAD OF UP THE FLUTES

There are many modified kinds of taps for specific uses, such as the gas taps, which are tapered to make tight fits for joints; the mudhole or boiler wash-out taps also taper for a similar reason. Boiler stay taps are very long, to tap holes "in pitch" or step in two plates separated by a considerable distance. Large sizes for marine boilers are of shell type, i.e. the two tap portions are mounted on a long bar with pegs which locate accurately, so that the threads will run in continuation. Taps for gas and water mains have a collar to prevent slipping into the interior, and the drill rimer taps have a drill point cut solidly on the end, or an inserted point, enabling the hole to be drilled and then tapped at one operation. Tap wrenches for ordinary service have a handle at each side of the square hole or holes, while for working into confined situations the single-ended pattern is essential. The adjustable wrenches, fitting several sizes of squares, are very convenient, but need to be well made and hardened for continuous satisfactory service. One of the best designs has a knurled sleeve, which is instantly turned with the fingers to open or close the movable jaw, Fig. 22.

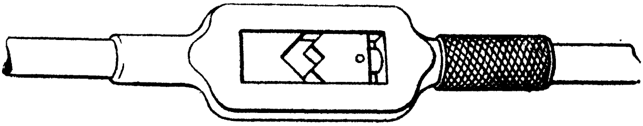


FIG. 22. A GOOD DESIGN OF ADJUSTABLE TAP WRENCH

DIES

The old-fashioned die stock, with two dies slidable in a groove, is still largely employed, especially for gas threads, but the convenient circular die, screwing at one going over, has greatly invaded its province. Such dies can be rapidly changed in the stocks (if a separate stock is not kept for each), they cut excellently, can be adjusted for easy or tight fits, and a guide can be readily fitted so as to make a true start. The solid screw plates are good for small work, carrying a number of sizes in each plate, but they are not always such free-cutting tools as the dies proper.

The two-die stock has either a separate screw, located at an angle to the pair of handles, to close the dies to the required size, or one handle forms the adjusting screw also. The gasfitter's stock of small size has a thumbscrew at one end, and it carries several dies in the slot. An improvement on the regular model for either bolts or gas threads is the Chatwin, Fig. 23, in which the adjusting handle has a fine-pitch screw, carried in a plain steel sleeve, with instantaneous locking device. This can be released in a moment, but while locked it holds the handle as though it were almost forged solid with the stock. The Whitworth guide-screw stock is an improvement on the usual arrangement of dies; it gives better contact around the threads right from the commencement, and ensures correct pitch.

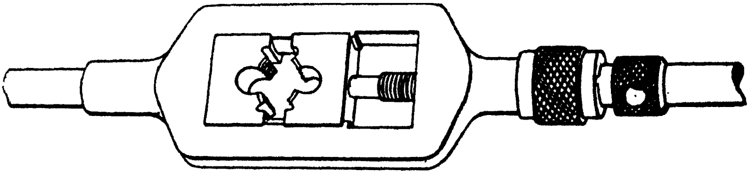


FIG. 23. STOCK AND DIES OF IMPROVED PATTERN WITH INSTANTANEOUS LOCK TO ADJUSTING HANDLE

(Thomas Chatwin, Ltd., Birmingham)

The circular dies may be either solid or adjustable, the variation in size in the latter case being effected either by a complete splitting into two, or by springing a partially split die with screw or wedge pressure. The manufacture is by cutting the threads, then drilling and finishing the openings which give the cutting edges, and relieving the threads for proper working clearance, similar to those of a tap. Some dies have three thread portions, some four, while the larger ones for fine threads possess six or more "lands." The adjustment of a spring die has limitations, because when sprung open excessively the relief is lost, the threads becoming parallel with those of the screw being cut. The mouth of a die has the threads partly cut away, like those of a first tap, for starting purposes. More accurate alignment may be ensured by the fitting of a guide, which either goes in the stock or constitutes part of a collet, in which the die is secured, Fig. 24. There are several methods of adjusting the split of a spring die or

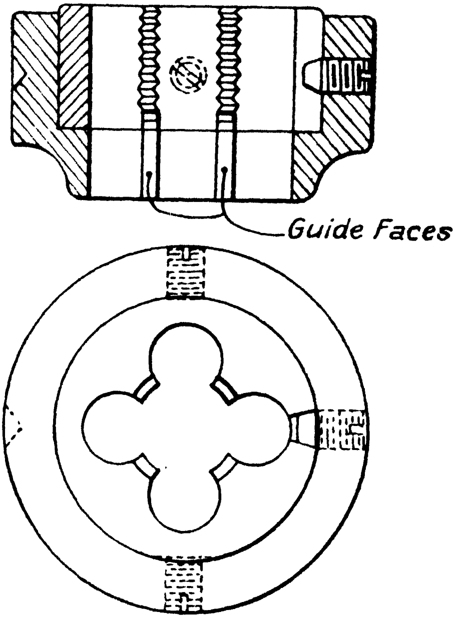


FIG. 24. DIE HELD IN COLLET
Also forming guide for true starting

a divided one, the favourite being a pointed screw, as this view reveals. On slightly retracting this the lateral screws will close the die in, or if these are loosened the other screw will open the die. Other devices are a tapered screw which forces open the split, and a plain taper pin with similar action. Some stocks are elastic, so as to compress the die after the adjustment has been made, instead of using lateral screws in the manner just mentioned. The dies furnished in halves are also adjusted by tapered screws, and possess the advantage that the cutting edges can be readily sharpened under a grinding wheel, which is impossible with a whole die. The only ways of dealing with the latter are by a small cylindrical, high-speed stone or roller, over which the die can be slipped and fed to and fro to grind the flat in front of each cutting edge, or to rub the flat with a carborundum stick. Half dies are also mounted in a slot in a circular collet (to fit in the usual stock), the halves being caused to approach by end-pressure screws, and locked with the face of the guide, which is screwed up from below. Another efficiently-working and readily-sharpened design consists of four flat chasers held in a slotted die, adjustment being made by a conical ring that pushes the chasers radially in their slots. When occasion demands that a die shall be turned in a confined space not admitting the full swing of the handles, a ratchet holder must be employed, as it often is in gas pipe work. The bit brace holder is also handy for the circular dies in some situations, being turned rapidly with the brace. But for most ordinary purposes, such as cleaning the threads of

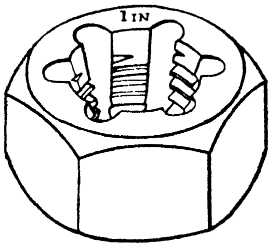


FIG. 25
DIE NUT, WORKED BY A SPANNER
To clean bruised threads in confined situations

studs which have become damaged while in place, carrying threads down farther, or to include in a tool kit for outdoor work, the simple and highly portable die nut, Fig. 25, is the thing, being either square or, preferably, hexagon to receive the spanner.

TOOLS OF THE LEVER CLASS

A great group of tools used by woodworkers, and still more by metalworkers, is of the lever type, mostly non-cutting. The principle is essential in order to provide sufficient power to pull, or twist, or sever. The cutting tools are mainly pincers, pliers, and shears—the first-named only to a slight extent, however, the shape being similar to the ordinary pincers for extraction of nails, but with the jaws ground to a cutting edge. Pliers occur in a great number of shapes and sizes, either for pure levering or bending, or for cutting, or the two combined in one instrument. Many trades have their special forms, and certain objects used in mechanism require a particular shape for access. The finest sorts are the round-nose pliers of the watchmaker and jeweller, who also employ special shapes for holding certain articles, and some to perform punching, such as at the ends of mainsprings. All ordinary pliers have a simple pivot joint, but there are some designs constructed with a toggle joint, which gives great power for squeezing or cutting. Some gripping jaws are plain, some with cross serrations, and the gas pliers have regular teeth for biting into iron pipe. Handles may be plain, or terminating in a screwdriver end, or a reamer, or a cone for opening out and smoothing purposes, while electricians' pliers are insulated with rubber or vulcanite sleeves. Most handles are forged, but those of one or two makes are stamped from steel plate ; a parallel jaw action, instead of the usual radial one, occurs in these. Detachable jaws enable replacements to be made, as well as convenient sharpening for efficient cutting. The Starrett is the best known of these, each jaw being held by a screw and serrations, these enabling the width of opening to be adjusted as required. As a rule, pliers should not be employed for turning nuts or set-screw heads, but it does not matter so much if these are black, and retention of good appearance immaterial.

Hand and pin vices are a class of tool related to pliers, being used for a prolonged grip where the hand would become fatigued. These vices also are of a more convenient body shape for slowly rotating the work while being filed or polished.

Spanners or wrenches are tools of universal use, and demand a high grade of manufacture to give continuous satisfaction. They should be drop-forged and properly hardened in the jaw, which should be of accurate size to prevent pulling the corners off the nuts and heads. For ordinary application the straight, single-ended or double-ended wrench suits, but if access is necessary to a difficult place the 15-degree angle type must be resorted to ; this enables a hexagon nut to be turned when the swing of the handle is limited to 30 degrees. The " S " wrench is also convenient for awkward access. Thin or lock-nut wrenches deal with thin nuts under thick ones, and for certain other fastenings where a very thin head must perforce be used. Usually, long handles are forged with the structural or bridge erectors' spanners, ending in a tapered end which is utilized to pull holes into line, while for tightening nuts of rail fishplates a long handle is likewise needful.

The box spanners are of two principal sorts, with the handle at right angles to the hole (as in an ordinary spanner), or with a long stem prolonged up to a convenient distance from the hole, so that the tool can be applied in sunken parts impossible to get at otherwise. The stem may be turned by means of a permanent handle passing through its top end, or by a loose podger. The tubular box spanners have gained much favour, not only for portable reasons (such as in a car outfit), but for general purposes. They differ from the older solid types in being pressed out of tube instead of cut from bar, the nut recesses in the latter class being made on an angular hole drilling machine. Various

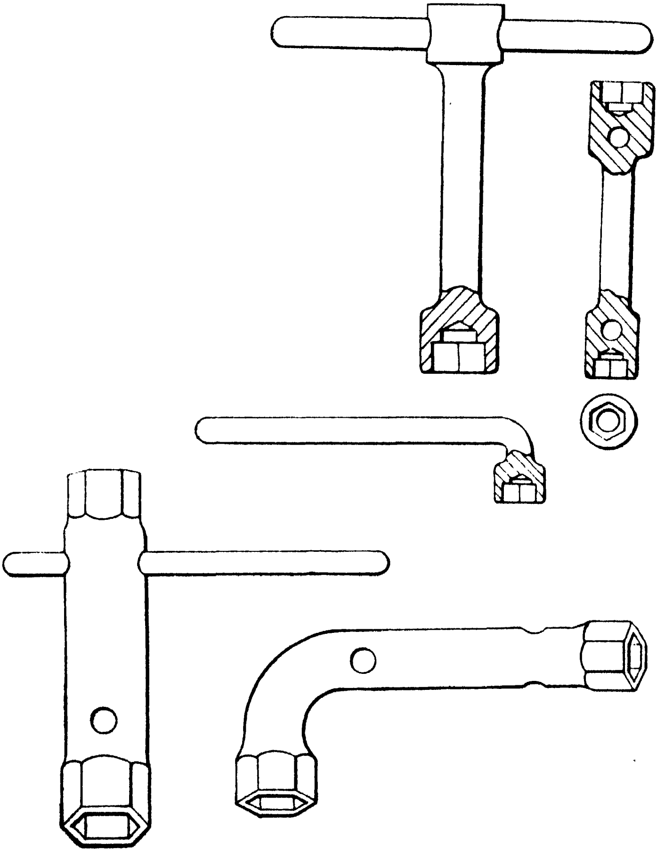


FIG. 26. VARIOUS SOLID DRILLED AND TUBULAR BOX SPANNERS

forms are shown in Fig. 26, while Fig. 27 deals with ratchet spanners, both of tubular kind and ordinary. Given good material and proper hardening, wrenches of any class will endure well without spreading much, and so damaging the corners of the nuts, but abuse is common, such as using a piece of pipe to increase the leverage, and striking the handle with a hammer. Either of these practices puts extra stress on the spanner beyond its designed duty. If it is necessary to loosen a very tight or rusted nut an old spanner should be employed, or a jarring effect obtained by striking with a blunt chisel near one corner of the nut to start it turning. Before this, some help may be had by pouring paraffin over to soak into the threads, or by dropping a white-hot nut of larger size over to cause sudden expansion of the tight nut.

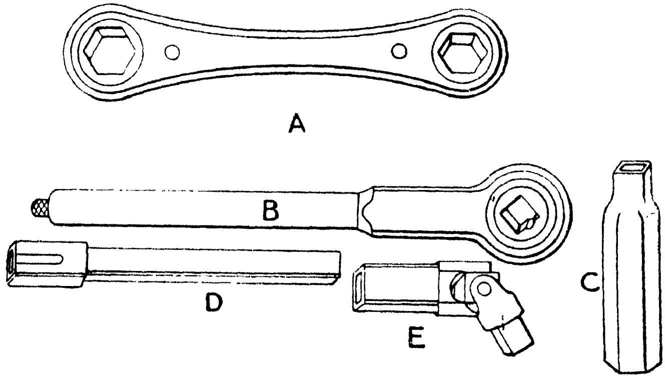


FIG. 27. TYPES OF RATCHET SPANNERS

A = Ratchet spanner for two sizes
B = Starrett reversible ratchet wrench
C = A long nut socket
D = Extension bar
E = Universal joint for difficult situations

It is always preferable to use a solid wrench for a continued run of similar nuts or heads, as in dealing with fastenings of tools or parts on a lathe or other machine, or in manufacturing processes where time is precious, in assembling parts, or in making repairs. To carry a stock of various sizes with handles complete, even in double-ended patterns, is not convenient when portability is essential, or in a small workshop where some sizes would be required only occasionally. Well-made adjustable wrenches therefore fill a very useful sphere, but cheap ones are to be avoided. The design should be such that the movable jaw always has adequate

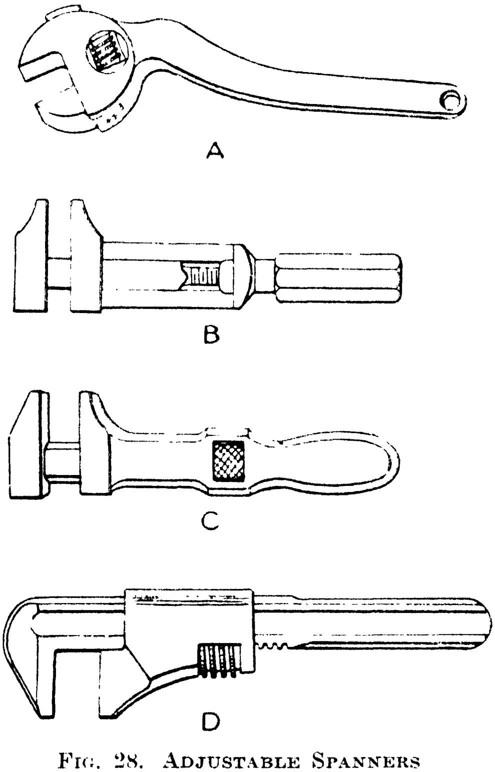


Fig. 28. Adjustable Spanners

A = Clyburn spanner
B = Coach wrench
C and *D* = Variations of sliding-jaw type

support against deflection, and the adjusting device must be free from backlash or tendency to work loose when the tool is moved in either direction. The Clyburn and the coach spanners are old-established designs, and well tried, though quite different in shape (Fig. 28, *A* and *B*). The tendency is now to enclose the slide of the moving portion so as to gain the fullest degree of support *C*, while in designs having the moving jaw slidable upon the handle a goodly length of bearing is given *D*.

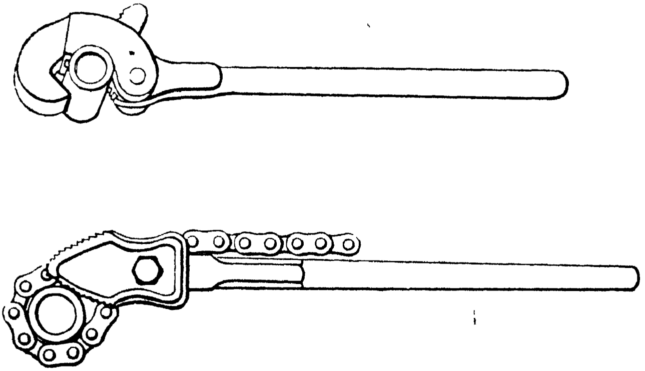


FIG. 29. SELF-ADJUSTING PIPE WRENCH (ABOVE), AND THE CHAIN TYPE (BELOW) WHICH HAS A LARGE RANGE OF CAPACITY

Pipe wrenches are sometimes solid, having a "V" opening with serrated faces, which grip into the pipe and enable it to be turned. The more favoured construction is one containing a pivoted jaw, automatically tightening the grip as pressure is applied at the end of the handle, one variation being sketched in Fig. 29. The chain wrench is very popular, because it fits such a wide range of diameters, such as (in different tools) ⅛ in. to ¾ in., ¼ in. to 2½ in, 1 in. to 6 in., 4 in. to 18 in. The motion of pressure on the pipe is reversed by loosening the chain and placing the jaw underneath the pipe.

Either a cable chain or a flat-link chain (as illustrated) is fitted. Special wrenches are made to grip smooth pipe, some having a leather strap self-tightening as the lever is pulled over ; or a good kind for brass and copper or nickel-plated pipe is built, very like a single-handle stock and dies, the equivalent of the latter being made with smooth bore, and receiving various diameters of split bushes to tighten around the pipe and hold without distorting or scratching it.

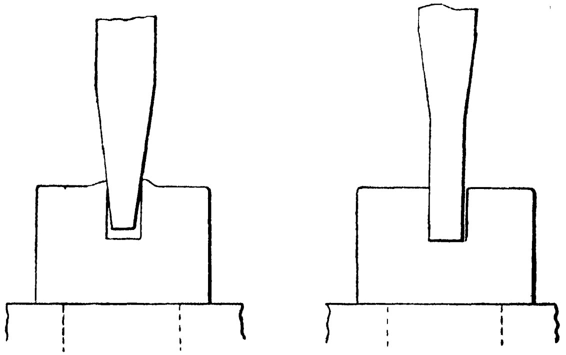


FIG. 30. INCORRECT AND CORRECT FIT OF SCREWDRIVER

Screwdrivers, though apparently the simplest of tools, are furnished in great variety : short, long, with different shapes of blades and contours of handles, in special forms for difficult access, as well as with ratchet or spiral action to save time. The short drivers are preferred by those dealing with small operations, requiring close attention, and the handles if not in wood are knurled for rapid twirling. In some high-class tools the blade is held in a chuck so that it can be changed, or reversed end for end to enable the driver to go in the pocket. For those who like to do nice work, whether in wood or metal, it pays to keep several drivers at hand, having different thicknesses of blade at the end ;

this enables a good close fit to be made in the particular slot being dealt with. The erroneous impression often exists that a tapered end will do quite well, but this always burrs over the slot (especially in brass screws) and spoils the good appearance. A parallel contact is the correct one, Fig. 30 detailing the differences. When a piece of work is being assembled and fitted and altered or tested, it is best to use temporary screws for parts requiring frequent disconnection during these operations ; then at the final polishing and putting together the proper screws in perfect condition are inserted.

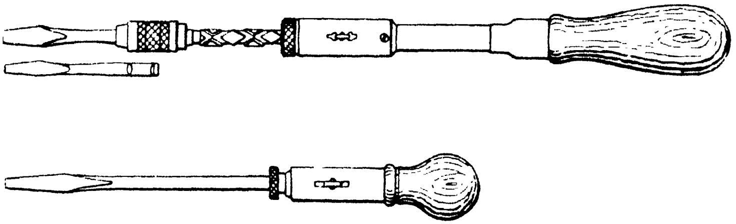


FIG. 31. COMBINED SPIRAL AND RATCHET TYPE OF SCREWDRIVER, AND RATCHET FORM ONLY

The carpenter's brace has long been utilized for insertion or removal of screws when fitted with a screwdriver bit. Where its swing is impossible, or a handier tool is required, the spiral driver is used, the screw being turned by pushing on the handle. Some include a ratchet action as well, Fig. 31, the change from right or left hand to either the spiral or the ratchet being made by moving the little slide from one end of the slot to the other. Or the blade can be set rigidly as in an ordinary solid tool. The ratchet drivers alone are highly valuable to save time and also for use in awkward places, or where one hand is wanted perfectly free. This type is also illustrated in Fig. 31.

Circumstances frequently arise, particularly in repair operations, where any ordinary screwdriver cannot be applied because of insufficient head room. It may not be desirable or feasible to effect any dismantling to enable a screw to be got at, while there are often cases in which a slight adjustment or correction has to be made to a closed-in screw. The corner or bent drivers are necessary for this work ; one blade lying in line with the shank, the other at right angles thereto, Fig. 32. An alternative sometimes possible is that of using a short bit of steel fashioned into a blade, and turning it with the pliers, or a shifting spanner closed in tightly. Or the top end of the blade may be enlarged into a hexagon, and an ordinary spanner applied. This idea is also valuable for turning very tight screws, because the spanner affords great power. Another way is to finish the top of the blade square and rotate it with a tap wrench.

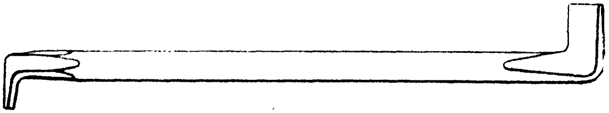
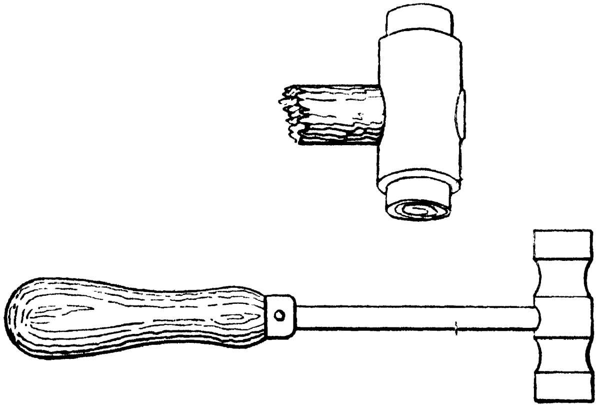


FIG. 32. DOUBLE-ENDED CORNER OR OFFSET SCREWDRIVER
For low headroom and confined situations

PERCUSSIVE TOOLS

These always effect their action by blows, resulting in the production of a certain degree of movement, which may cause either a tool or a portion of work to move. The latter statement includes actual displacement of metal, as in forging, welding, riveting, caulking, punching, or a bodily change of position, such as when parts are fitted together tightly or separated by blows. Action on tools comprises that for chisels for wood and metal, punches to make or enlarge holes, or centre punches, drifts to enlarge holes or pull them into line for insertion of rivets or bolts, snaps to close and finish the tails of rivets, and caulking tools which seal up a joint closely. Carpenter's and joiner's mallets have flat sides and ends, but mason's and woodcarver's are circular and coned in shape. The rawhide mallets are also termed hammers ; they are necessary to jewellers, workers in brass and other soft materials, and to fitters and machinists, for striking blows where injury to the surface is forbidden. Some are made up in the form of a roll of hide, through which the handle is inserted ; weight may be increased without having the head inconveniently large by rolling up a central strip of soft metal with the hide. Easy renewal of worn faces is provided in the hammer sketched in Fig. 33, new faces being just made a tight fit in the shell. An intermediate stage between these soft tools and the hardened steel hammers occurs in the brass, copper, aluminium, lead and whitemetal hammers. Generally the handle is fitted in much the same way as for a steel head, but lead and babbitt heads are often cast around a tubular handle. These soft tools, used to strike on finished



FIGS. 33 AND 34. RAWHIDE HAMMER WITH RENEWABLE FACES (ABOVE), AND BRASS HAMMER (BELOW)

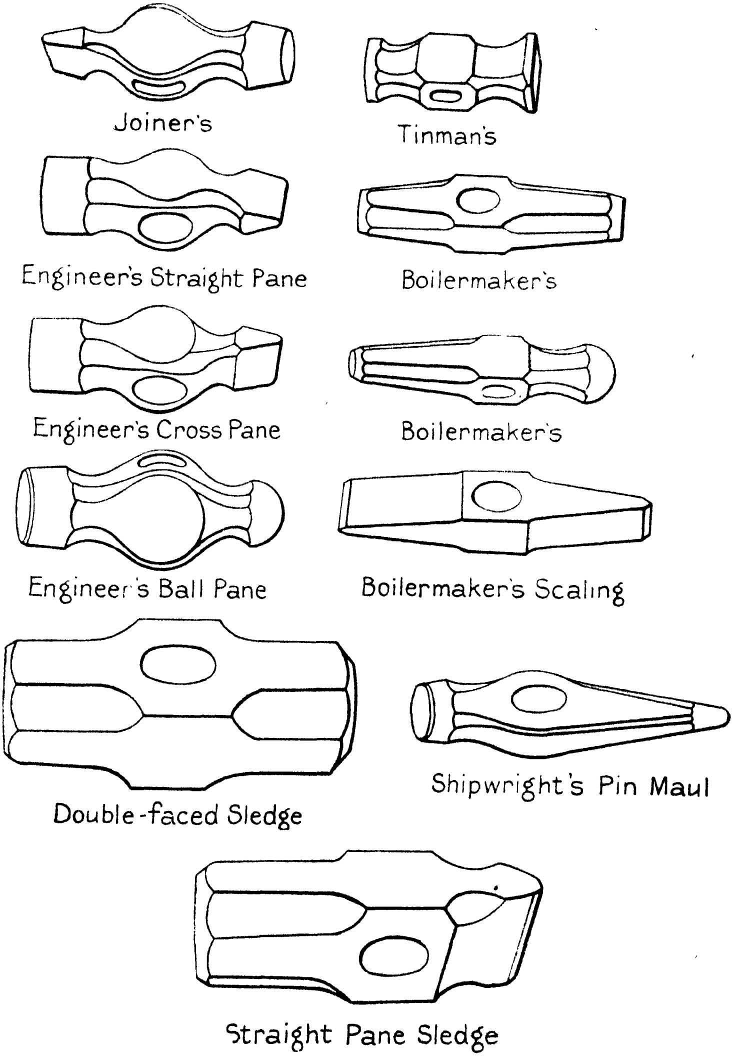


Fig. 35. Various Hammers used for Wood and Metal Working

surfaces, become deformed fairly soon, hence the casting method is convenient. Brass hammers of nice shape, Fig. 34, are obtainable. Sometimes a gun-metal head has recesses to pour in whitemetal, and so provide for renewal, while another style is a steel head with recess at the one pane to receive a copper insert.

The standard steel hammers are furnished in great variety, many having special names, and others designated by the kind of pane, such as straight pane, cross pane, ball pane, each being specially useful for getting at certain positions, or driving nails or brads, or doing riveting. The heavy sledge hammers also have these three classifications. Many peculiar shapes of bodies and of panes are found in certain trades, such as tinmen's, coppersmith's, boilermaker's, sawsmith's, quarrymen's, and other occupation. Handles likewise vary greatly in shape, length, and the mode of termination at the end. A few typical hammers may be noted in Fig. 35, but some trades use several slightly modified specimens of a basic type, such as in boilermaking and plating. Most of these are long, but either have ordinary round panes, conical ones, ball panes, or cross panes curved backwards. Much of the work is difficult to reach, hence the long bodies. Tinmen also require a variety of shapes for planishing, hollowing, creasing, riveting, and so on.

✓ The smith's fullers and set-hammers are the equivalents of hammers, but as they cannot be properly used on the work by a self-directed blow, they must be laid on and moved about to successive positions, while the percussive effect is delivered with a hammer or hammers by one or two strikers. The fullers, either to rest in an anvil hole or to hold with a handle or withy rods, have rounded edges to beat into the hot metal in a series of grooves, and so reduce its thickness rapidly. Then the set-hammer or flatter is applied to eliminate the corrugations and produce a smooth flat surface. Swages reduce round sections, such being illustrated in the group, Fig. 36, along with the other tools just mentioned. Snaps for closing rivets over neatly are really a class of set-hammer ; the body is either held with the hand direct, as for tinmen's and coppersmith's work, while the head is struck by the hammer, or for boilers and plated work a withy handle must be attached. Caulking tools resemble cold chisels, but have square blunt noses matted to bite into the edge to be caulked to make a tight seam along a riveted joint or around a rivet, or to caulk lead into pipe joints. The shipwright's caulking tool is different, being very thin at the edge.

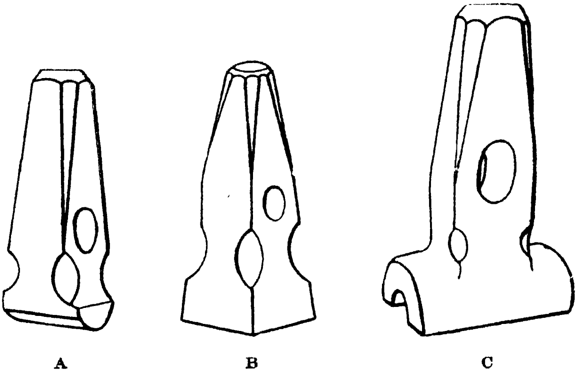


FIG. 36. SMITH'S TOOLS FOR REDUCING AND FINISHING HOT METAL ON THE ANVIL

A = Top fuller for rapid drawing down
B = Flatter for smoothing surface after fullering
C = Top swage for drawing down round sections

There are several sorts of drifts, including the parallel one for driving into tubes to correct circular faults, the plumber's coned-shape, and the boilermaker's tapered drift, which is driven through matching holes to pull parts into line, the flat-sided taper drift, with which the fit of a drill shank or socket is separated from the spindle, and the square-toothed drift or broach, Fig. 37, driven through a drilled hole to make it into a square one. Some drifts are smooth-sided and cut on the ends only.

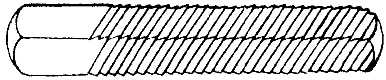


FIG. 37. SQUARE DRIFT

This is driven through a drilled hole instead of using the file

Punches comprise numerous styles, some making an impression in wood or metal, such as for decorative purposes, others driving in parts, as brads in wood, or pins in metal, or removing the latter kind for repair operations, driving out old rivets, and generally punching at parts which cannot be reached with a hammer of any kind. The woodcarver's punches are the most elaborate styles of the decorative class, impressing all kinds of pretty ornamentations. The brad or pin punches are plain and of various lengths, with circular or square cross-section. Hole punches occur in different types, according to the màterial and the size and depth of hole. A perforation can sometimes be effected by just driving the punch against the work,

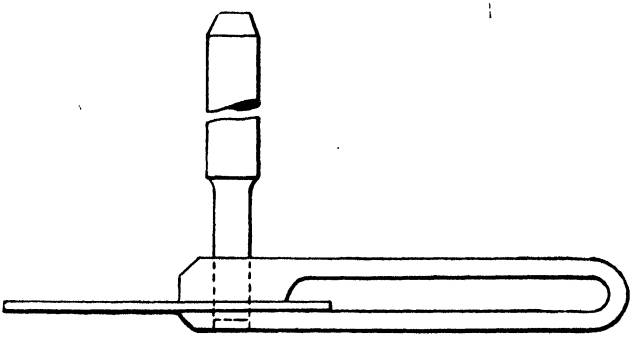


FIG. 38. HAND PUNCH, WITH GUIDE AND BOLSTER COMBINED

as in certain sheet metal processes, or in smithing hot metal, and in the saddler's and tinmen's hollow punches. Yet it is often impracticable to make a neat hole unless the sheet is supported by a bolster, as in punching machines ; the hand equivalent of this may be observed in Fig. 38, which is thrust on to the stuff to the position desired, the punch placed in the top hole and driven with the hammer so as to force the punching down through the lower or bolster portion. The principle is applied likewise to various pliers which make holes in leather, paper, cloth, rubber, tin, brass, etc., there being always a support for the material. Some pliers do one size, others have removable punches of various sizes, while for instant change the revolving or turret designs are available, a set of punches being held in a revolving head.

The centre punch is a tool of universal demand in metal working to mark impressions on straight or curved lines or circles, and afford a start for a drill. The end should be tapered down as small as possible consistent with strength in order that the view may be unobstructed, and the body is either square or octagon or knurled to prevent rolling. Special punches include those with parallel ends to fit down into drilled holes, and so mark a centre pop on the work for drilling by (Fig. 39). The spacing punch again has two points with an adjusting screw to vary the pitch, and so enables pops to be spaced uniform distances apart for drilling and cutting out sheet metal pieces and dies, etc. The bell-centring punch marks a centre on the end of a shaft for drilling to put in the lathe, the punch being a sliding fit in the body. Those who have to mark a great number of successive pops, as in lining-out work for machining, or sheet metal and dies for cutting out, are better served by the automatic punches than by the ordinary sort and a hammer. There is a coiled spring which is set up when the body of the tool is pressed down when the point is in contact with the work, and after the stroke has been attained a catch becomes released and the spring delivers a kick to drive the point in. All punch marks are of a uniform depth, an important thing in fine work. In one design the blow can be regulated from light to heavy, the latter for making pops for drill starting.

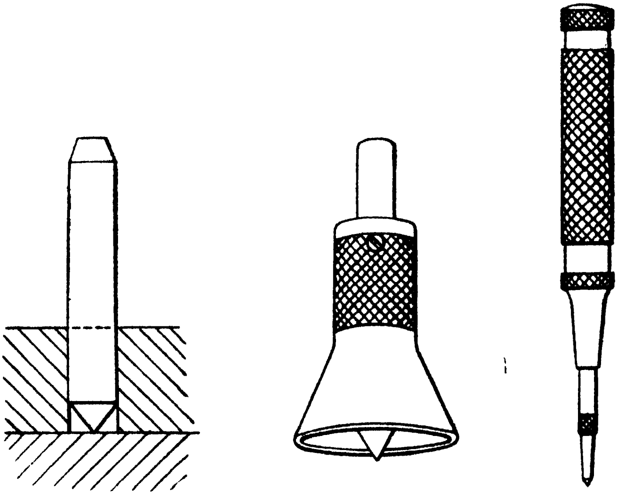
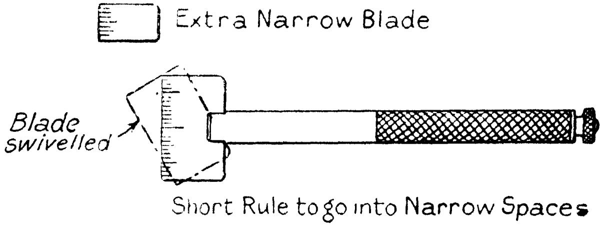


FIG. 39. TYPES OF PUNCHES

Centre-punch to mark from drilled hole on to work below (right)
Bell centre-punch to put pop centrally on a shaft end (centre)
Automatic centre-punch requiring no hammer (left)

MEASURING AND GAUGING TOOLS

In strictness, measuring and gauging processes are different, the first being done with an adjustable class of tool or a rule device, the second with a fixed gauge for one size only. This distinction is not adhered to very closely, however. Generally speaking, the measuring tools are employed for a miscellaneous range of treatment in workshops making varied products, and the fixed gauges for repetition work, this, again, being subject to qualifications. The difference is partly to do with time-saving, partly certainty of accurate conditions. A measuring tool which has to be adjusted to size is both a time-consumer and an element of error, whereas the fixed gauge suffers from neither of these faults. A maintenance system has to be installed for the fixed gauges, so that they may be periodically checked and rectified when worn or damaged.



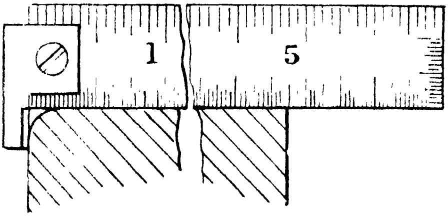


FIG. 40. HOOK RULE, TO MEASURE OVER ROUNDED END OR THROUGH A HOLE TO THE BACK FACE

The oldest form of measurement in workshop practice, that of the rule, still has immense application in wood and metal processes, but is displaced in a great deal of high-class metal work such as tools, brass fittings, valves, typewriters, cycles, motor-cars, engines, pumps, and all sorts of machines made on the interchangeable system. No rule measurement, however carefully applied, is able to test the sizes of components to anything near the degree of accuracy demanded.

Neither would the method be economical, if practicable, while other forms of measuring tools were available. The engineer's tool-maker, however, uses high-class steel rules for many purposes, and obtains very good results on constantly varying subjects.

Rules for woodworkers are made in careful fashion to reduce risks of warping, the best being of boxwood, completely bound and edged in brass. They are mostly of twofold or fourfold construction, the non-folding types being chiefly used for bench work. The best steel rules are engine-divided and tempered, while stainless ones are also made. Flexible rules are handy for dealing with curves, and special narrow ones for slots and holes. The short rules go into grooves and parts of dies, etc., where no other will, the handle enabling the tool to be manipulated, Fig. 40, which also shows the hook rule, applied to measure over the end of a piece which has a rounded corner, or through the bore of a piece of work. Keyseat rules are " V " shaped in cross-section, to be laid on a shaft to mark parallel lines as for a keyway.

Although a good steel rule may be used as a straight-edge, to test flatness of pieces, or alignments, a proper straight-edge is preferable. This is made and kept in the best condition, being of hardened steel in the smaller dimensions, and of cast iron, with deep, well-ribbed frame for larger sizes. The surface plate is another testing appliance, truly scraped to match a master plate, and is utilized to test the truth of valves, parts of machine slides, etc., which have to be scraped to make a more perfect contact than is left from the machining process.

A convenient adaptation of the steel rule for taking measurements is the caliper square, Fig. 41, in which the sliding jaw is first set approximately to the division required, and then finely adjusted by means of the screw on the auxiliary head. Finer readings may be taken if the tool has a vernier fitted, shown in the detail, Fig. 41. The caliper beam is graduated into fortieths of an inch, every tenth of an inch or fourth division being numbered. The vernier plate has twenty-five divisions, which occupy the same distance as twenty-four divisions on the beam. This means that there is a difference of

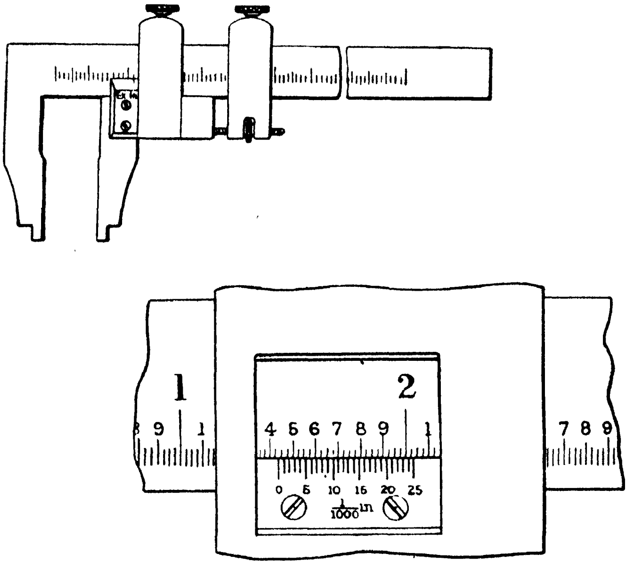


FIG. 41. CALIPER SQUARE FOR EXTERNAL AND INTERNAL MEASURING, AND DETAIL OF VERNIER FITTING FOR FINE READING

1,000th in. between one of the beam spacings and one of the vernier spacings. To read the dimension to which the jaw has been set, note how many inches, tenths, and fortieths the 0 mark on the vernier is from the first graduation or 0 mark on the beam, then count along the vernier divisions until a line is found which coincides with one on the beam (the eleventh line in the diagram), and add this number of thousandths to the reading on the beam.

Special kinds of calipers are made, such as for measuring gear teeth and thread tools. And a modification with a narrow sliding rule is used to measure depths, the graduations being either ordinary or with vernier scale, the latter for the higher grades of precision work on tools, dies, and fine work. The graduations are either in English or metric system or combined, each edge reading to the respective graduations. Micrometer depth gauges will be dealt with later.

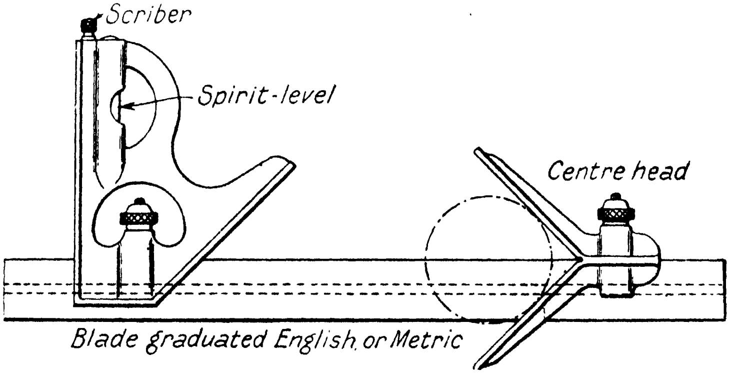


FIG. 42. COMBINATION SQUARE
With heads adjustable along beam

A further highly-valued tool, which includes a tempered steel rule as its basis, is the combination square or set, the face of the rather thick blade being grooved in order that certain heads may be clamped accurately to it. The rule divisions often come in useful for taking lengths and depths, but for a great many purposes the beam just answers as a straight-edge, or the longer blade of a square. The standard head, which converts the tool into a precision square, Fig. 42, combines a 45-degree angle and a spirit level, also a hole to store a pointed scriber. The centre head enables the centres of circles, such as on shaft ends, to be accurately found. A protractor head (not shown) completes the outfit. In some cases the edge of the blade or of one of the heads is laid against the work itself, in others the base support is a part of a machine (a table or slideway), or a surface plate or marking-off table forms the datum surface, this enabling pieces to be lined-out for machining, and afterwards tested or adjustments effected. The spirit levels constitute an additionally valuable feature for certain sorts of settings or tests.

Tools that do not embody any kind of rule divisions, or only in certain instances, comprise the squares and the bevels. The first-named are graduated principally for carpenters and other woodworkers, also millwrights, but in machinist's work the plain blades are more common. A handy tool, however, has a relatively short and thick blade, with a groove along it similar to the combination square, and the stock is just a parallel block for right-angle testing. The adjustability of the blade makes it convenient for getting into places where a fixed blade could not go. A blade with bevel ends may be substituted for 45-degree and 60-degree angles. The smaller solid squares have the stock united to the blade with permanent rivets, but the larger sizes are attached with several screws fitted in such a manner that the tendency is constantly to press the blade against the stock and maintain the accuracy. Future rectifications can thus be easily made at the works. A class of adjustable square is that needed by diemakers, to obtain angles of clearance or draught. The narrow blade in this can be swivelled up to about 8 degrees, the amount being shown on a pointer.

Bevels have either a wooden stock and steel blade (for woodworkers) or are completely of thin steel. One of the most useful of the latter type has the blade offset (Fig. 43) so that any angle, however slight, may be obtained, which is not the case with the ordinary straight-blade construction. The combination bevel, also illustrated, has still more range of usefulness, for scores of different relative settings of the parts, either to mark outlines or to test the angles of pieces of work, as gears, slides, tools, etc. To deal with the finest precision work the universal bevel protractor is made; this has the blade swivelled by a graduated dial, a vernier enabling the user to read to a fineness of five minutes, or one-twelfth of a degree.

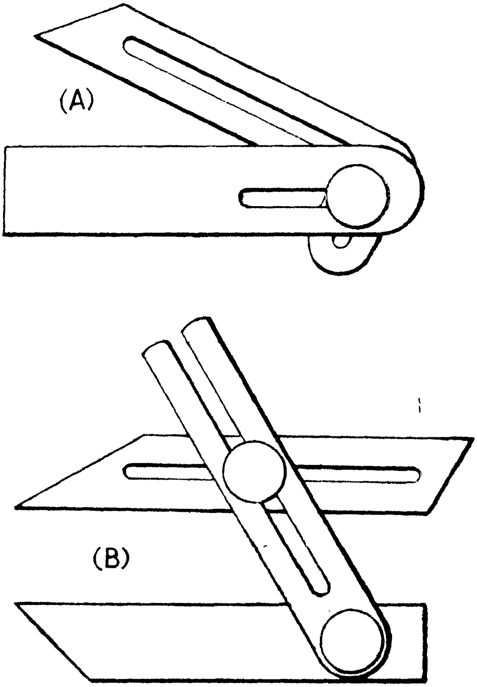


FIG. 43. TYPES OF BEVELS

(*A*) = Bevel with offset blade to give slight angles
(*B*) = Combination bevel which allows of very numerous settings

CALIPERS

Previous to the introduction of the micrometer caliper, the simple-jointed leg form was in universal use for measuring shafts and spindles, and thicknesses of flat articles, while the straight-leg type dealt with holes. There is still a great demand for these tools, but the micrometer is so easy to read to exact dimensions to the thousandth part of an inch, and sizes can be repeated without trouble or error, that it considerably displaced the old tool. The leg calipers are either set by a rule, or from a standard gauge or sample piece, or the size of a shaft is calipered and the internal caliper set thereby. Slight errors are always to be feared, unless the calipers are of the best construction, with the tips correctly formed, and used by an expert. Faults are chiefly weak springy legs, poorly-fitted or adjusted joints, roughly-shaped tips, and applying the caliper angularly to a shaft or a bore, instead of exactly normal to the length. Big calipers are particularly liable to spring, while even the weight of leg will cause sag, hence it is safer to measure with the pivot uppermost instead of down horizontally. The sense of touch must be very delicate to tell whether the tips are making just the right contact—any forcing is fatal—while a tight grip on the caliper also destroys the delicacy of touch.

Joints are important as regards the smoothness of fit and uniform tension at all parts of the movement. The insertion of a fibre washer or two gives a very smooth action. The best designs are supplied with a bolt fastening, the stud being flatted to fit the hole in one leg so that it cannot turn during tightening or loosening to correct the tension (Fig. 44). A triple joint of similar fashion is fitted on the screw-adjusting calipers similar in principle, however, to the ordinary two-leg tool. The adjusting feature, especially nice for setting large calipers, consists of a short leaf which, when pushed or pulled by the knurled screw, moves one leg, as it fits on the same squared part of the stud. Lock-joint transfer calipers likewise possess complication at the joint because, on loosening a large binding nut which clamps the joint, one leg may be swung away, after calipering over a flange or inside a chambered cavity, and afterwards swung back to give the measured size, against a stop formed by the auxiliary short leaf. Fig. 45 represents this tool. Hermaphrodite calipers have one turned-round point and one sharp or compass point, being used to mark distances from edges, find centres, test centres in holes, etc.

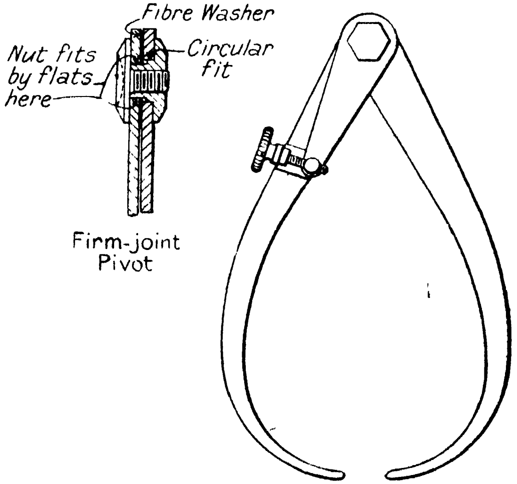


FIG. 44. CALIPERS WITH ADJUSTING SCREW

The spring calipers and dividers, with flat or square-section legs, or round tapered ones, are liked by toolmakers for their fine work. In the round and square-section legs the adjusting screw goes through these, but studs have to be fitted on the flat legs. In order to compete with the usual pivoted leg tool, instantaneous release of the nut is essential, this being done by making the internal part like a split chuck, with four springy jaws. When the legs are pinched together with the hand the jaws open off the thread, and the nut can be slid along freely, but when the legs are allowed freedom they cause the interior cone of the washer (Fig. 46) to contract the jaws on to the thread, and make the nut act as though it were solid. Specially broad tips are formed on the thread calipers, to span over more than one thread.

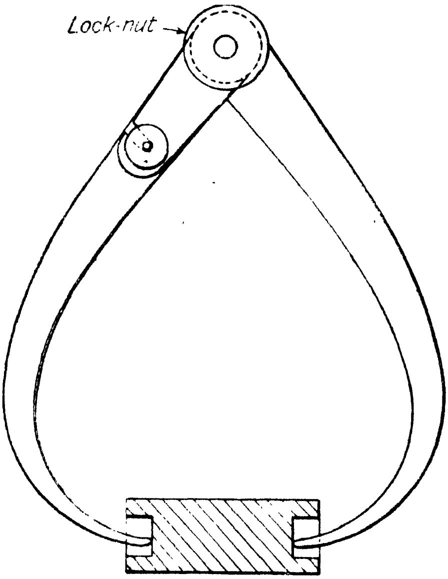


FIG. 45. LOCK-JOINT TRANSFER CALIPER

MICROMETER CALIPERS

The fine screw and graduated thimble which constitute the principle of the micrometer are applied in diverse fashions to measure external and internal surfaces, depths, as well as difficult pieces which cannot be reached with the ordinary shapes of frames and tips or anvils. In every type, however, there is the screw of high precision, 40 threads to the inch, so that one revolution of the spindle moves it one-fortieth (twenty-five thousandths) of an inch. Lines are marked on the sleeve (Fig. 47) at intervals corresponding to each fortieth. The bevelled edge of the thimble

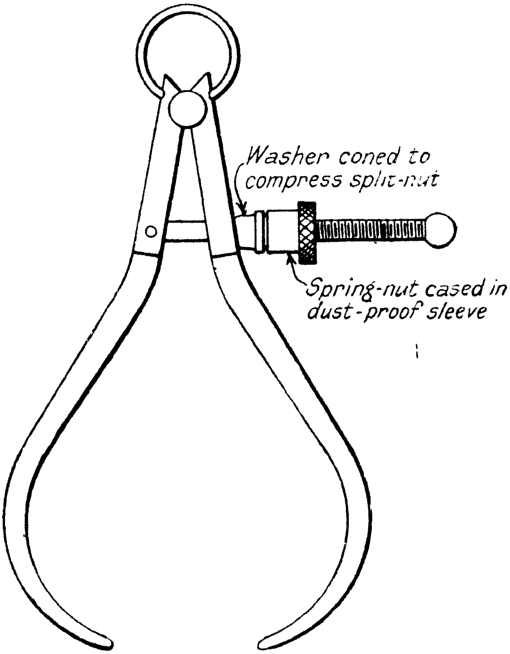
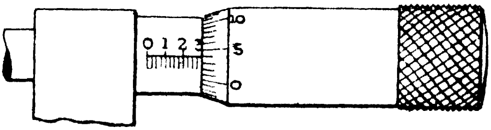

Washer coned to compress split-nut
Spring-nut cased in dust-proof sleeve

FIG. 46. SPRING CALIPERS FOR FINE WORK
With quick-adjusting nut

has twenty-five graduations around it, each fifth line being figured. A movement from one of these lines to the next gives one-thousandth of an inch travel of the spindle, hence the size of the setting can be read by noting the number of the vertical lines exposed, and adding the thimble divisions.

With a little practice one can read off the size almost at a glance, but a time-saver is the direct-reading micrometer with an index showing the number of thousandths (similar to a counter) giving instant results and avoiding the possibility of wrong reading.

Half and quarter thousandths can be estimated by moving the thimble part of the distance from one division to another in an ordinary micrometer, but the vernier principle is applied when much fine work is dealt with, this indicating a movement of one ten-thousandth of an inch.



Micrometer set to ·304

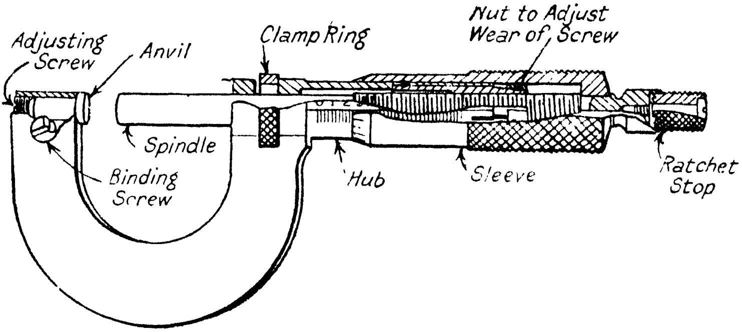


FIG. 47. PARTS OF A B. & S. MICROMETER CALIPER
Reading to 1/1000th of an inch

The elements of a caliper (Brown & Sharpe) are detailed in Fig. 47. The anvil is furnished with adjustment to compensate for wear on the measuring faces so that the spindle will touch it as the graduations read zero. The clamp ring binds the spindle when adjusted and prevents the setting from altering. The slotted nut becomes closed around the screw when its encircling nut is tightened, to absorb all slackness. Two purposes are served by the small ratchet stop: one is ease of rapid twirling (due to the small diameter) for quickly moving the spindle, the other slip which takes place when the spindle touches the work, so ensuring uniform pressure at all times and by any user. For convenience, the travel of a micrometer spindle is limited to 1 in., or in metric measure, 25 mm. Greater spans are calipered by a modification of the frame, that is, a 2-in. tool measures from 1 in. to 2 in.; a 3 in. from 2 in. to 3 in. and so on, up to very large capacities. The range of a single frame may, however, be extended by sliding or interchangeable anvils. The former is put in 2-in. micrometers, and deals with from 0 in. to 1 in. or 1 in. to 2 in. A lot of sizes are possible with a large frame and a set of anvils; these are held in with a nut (Fig. 48), and each is separately set and if necessary corrected at any time by the use of the lock-nuts.

Amongst the special anvils are those for thread calipering, a vee supporting the screw, while the spindle has a point, and the ball-shaped anvils, which reach against the wall of a small tube and give an accurate locating influence, impossible with a flat face. Paper and card must be gauged with specially large anvil faces so as not to compress the material and give a false reading. To reach into confined places it is necessary to have a frame with the anvil arm much narrower than usual. A method of getting a range of measurements from, say, 0 in. to 6 in., is by means of the beam micrometer of similar construction to that shown in Fig. 41, but with just the inch lines to set by and a micrometer head at the top of the moving jaw.

Internal micrometers are cylindrical in shape, embodying the 1 in. or 25 mm. range, the necessary span being made up by extension rods. Some micrometers of this class only have a travel of ¼ in. or ½ in. The larger kinds are made in tubular style for the sake of lightness. Fig. 49 shows a simple design, with ¼ in. travel, and measuring from 2½ in. to 9 in., with the assistance of the four extension rods, which are held in the split chuck. Bores up to about 9 ft. are measured with the large instruments. The micrometer depth-gauge consists of a barrel similar to that of the foregoing illustration, but with provision for extending one or other of a set of rods through a foot which rests on the work. In the specimen, Fig. 50, the screw has a movement of ½ in., and the adjustable rod is graduated into half-inches, these being cut in deeply so that the clamping fingers of the chuck automatically locate each setting positively.

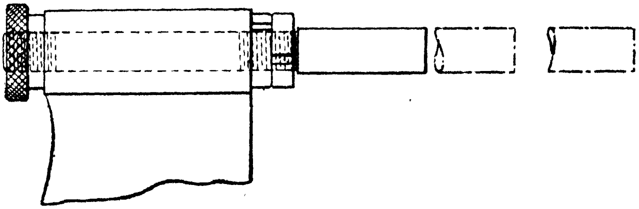


FIG. 48. METHOD OF FITTING REMOVABLE ANVILS FOR LARGE MICROMETER

Each anvil has its lock-nuts for adjustment to compensate for wear

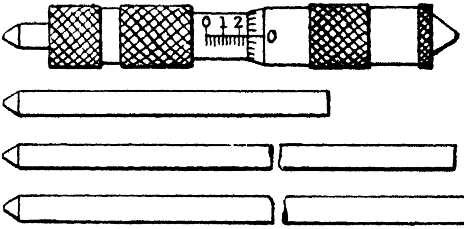


FIG. 49. INSIDE MICROMETER GAUGE

With four extension rods giving a range from 2½ in. to 9 in.

SOLID GAUGES

What may be classed under this heading comprises all the non-adjusting types, that is, the tool is either made solidly, or has anvils set to a certain dimension and used for no other. Such forms include the notched wire gauges, for wire and sheet, the circular external and internal, or plug and ring gauges, for plain fits or for threads, the flat gauges, cut out of sheet metal, or drop-forged, and the end measures, either cylindrical or rectangular. All such gauges are finished more or less accurately (according to the class of product dealt with) by grinding and lapping. The plug and ring gauges are either applied direct to the work, or are used to set calipers by, or test the truth of shop gauges. Reference discs are, however, made specially for reference purposes, being narrow and used with handles ; these are not supposed to be employed in the workshop.

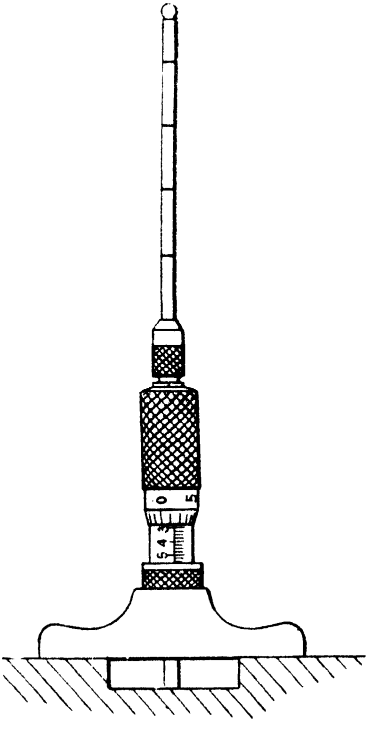
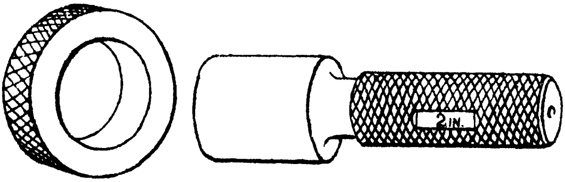


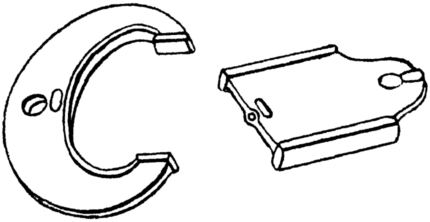
FIG. 50. MICROMETER DEPTH GAUGE

With rod having half-inch settings

Small gauges and those up to moderate size are made from solid steel, but lightness has to be studied in large units, and the plug gauge is either hollow, or is attached to a hollow handle, or both. Lately even the small plug gauges have been made in attached fashion, this with the idea of reversibility ; as one end wears the plug is unscrewed from its handle and turned end for end. The standard ring and plug, also the drop-forged



Ring and Plug Gauges



Drop-forged Snap or Caliper Gauges

Fig. 51. The Alternatives in Standard Solid Gauges

flat gauges are depicted in Fig. 51. Great care must be exercised in the use of all such tools, neither to drop them nor let them knock about with other hard objects, nor apply them to work in motion, nor use force or blows. Thread gauges are supplied in plug and ring patterns, either solid or with fitted parts for renewal or for the sake of lightness. The rings are often adjustable somewhat like a split screwing die, Fig. 52.

The limit gauges, in universal employment in factories, do what is impossible with the standard gauges just considered, i.e. control the size of pieces a definite amount above and below standard. Such is very small in the best work, say, a 5000th part of an inch each way, but coarser for general work. Hence, if the component is " held " within these limits, it will be certain to fit its mating part in the mechanism on assembling. Limits are necessary because of the practical impossibility of making things to exact size. Wonderful results are attainable in finishing the finest kinds of precision gauges, but such workmanship is not feasible in general manufacturing of miscellaneous parts. The limits are therefore determined according to the class of article made ; they would be coarser, for instance, on a large machine or engine than on a typewriter or sewing machine or rifle. The internal

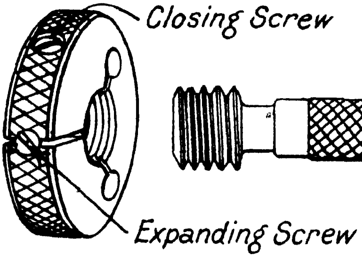


Fig. 52. Adjustable Ring and Solid Plug Gauge for Threads

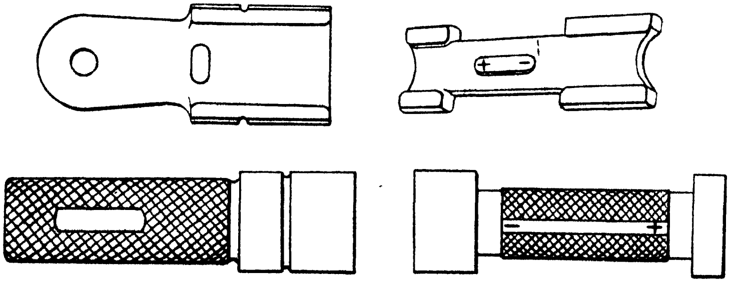
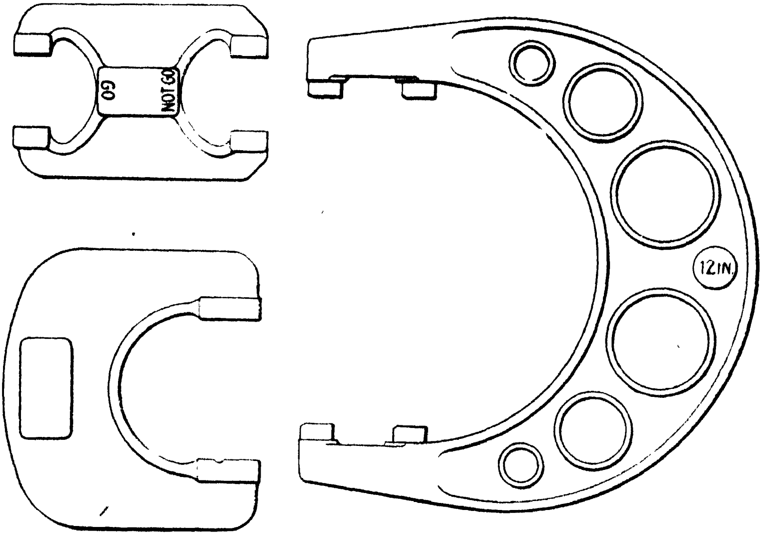


Fig. 53. Types of Internal Limit Gauges, Flat and Cylindrical

gauges are usually solid (non-adjustable), occurring in various forms as outlined by Fig. 53, and if external in shapes as per Fig. 54. But the adjustable snap is preferable for three reasons. The limits can be readily changed to suit new work or altered specifications. Entirely new sizes can be obtained from the same frame. The effects of wear may be compensated for. Cylindrical plugs are accurately fitted in holes in a cast iron frame, and are adjusted endwise each by a screw, while a lateral screw presses against a flat and locks the plug after setting, as well as preventing it from turning in its seating. The adjusting screws are sunk in sufficiently to allow of sealing-wax being poured in. This is' stamped with a seal, and tampering with the size of the gauge is thus impossible without detection.



Drop-forged styles for moderate sizes

Cast frame with lightening holes and inserted anvils. Suitable for large dimensions

FIG. 54. SOLID LIMIT OR TOLERANCE GAUGES OF EXTERNAL CLASS

The Johansson gauge, with these features, appears in Fig. 55. The anvils are either parallel, as drawn, or have enlarged heads, to reach against a shoulder. The reason of the bevel edges is to guide the gauge squarely on to the work. The insulated grip prevents the heat of the user's hand from distorting the frame.

The adjustment of such a limit gauge, as well as the checking of other types, may be by means of a precision measuring machine, or gauge blocks can be utilized. These are lapped steel blocks of a very high order of accuracy, and made in various thicknesses so as to give a large range of sizes with different combinations.

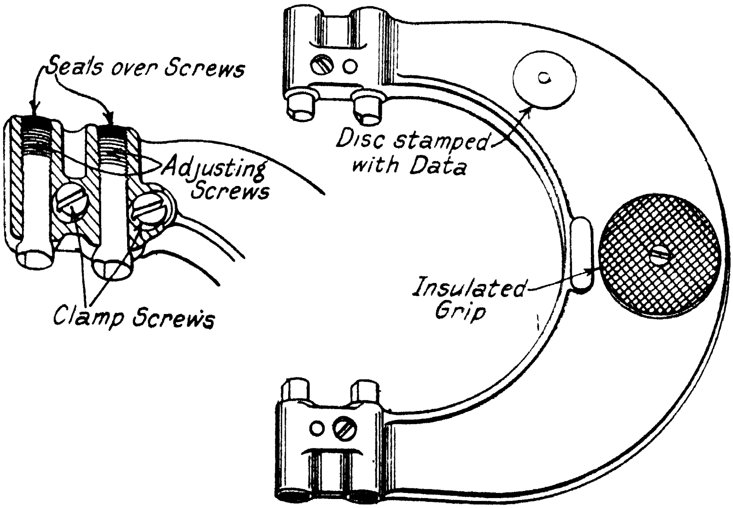


Fig. 55. Johansson Adjustable Limit Snap Gauge

For many purposes it is sufficient to bring these gauges together and use as a solid block, to test heights, set gauges, and for other functions. Holders are furnished for purposes where it becomes necessary to hold a batch of blocks with two of them projecting, for internal or external tests. These holders have each a slot to place the blocks along, and an end pressure screw to clamp them. A base may be attached to use the blocks for measuring heights from a surface plate.

Contour or profile gauges are made from flat steel, and gauge the outline of a piece of work, such as the length and shape of a screw head, the lengths and diameters of a shouldered pin or spindle, etc. Such gauges must be made to suit requirements ; the only standard tools of this class available are the fillet gauges, which merely test internal and external radii.

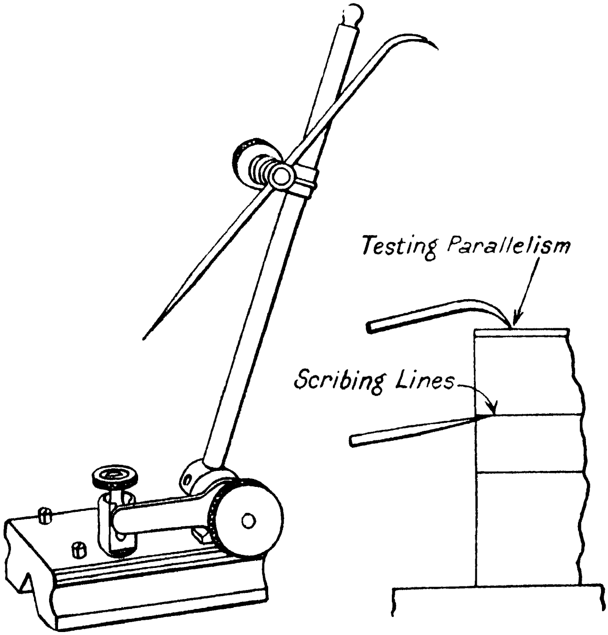


FIG. 56. SURFACE GAUGE, AND THE PRINCIPLE OF ITS USE FROM A LEVEL SUPPORTING SURFACE

SURFACE GAUGES

These do not measure of their own accord, but are of the transference class. They will show whether two or more heights are alike from the datum surface (a marking-off table or surface plate), or whether work is equal in height to a standard, such as a reference block. For scribing lines also, the needle is greatly in demand, because all such lines run parallel to the marking-off table, no matter how rough the under-surface of the casting or forging is which is packed up

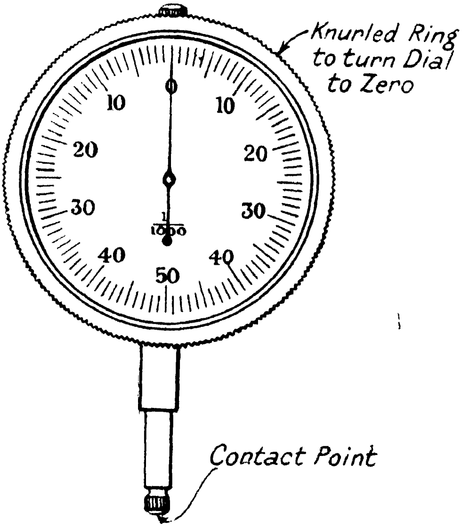


FIG. 57. TYPICAL DIAL GAUGE, USED FOR TESTING FINE DIFFERENCES

on the table. The Brown and Sharpe design, Fig. 56, represents a good example with a pivoted spindle. After tightening the knurled nut on the boss, the fine adjustment may be brought into use to rock the spindle very slightly, and so alter the height of the needle. The vee-groove in the base enables this to be rested on a cylindrical surface, while the two pins can be pushed down to slide along against the edge of a surface plate or of a tee-slot.

TEST INDICATORS

The value of these has been more and more appreciated of late, as a means of delicate perception of fine differences. In many cases the precise degree of difference is not necessarily of interest—it is sufficient to know that there is a difference, as evident from the displacement of the needle. But in a large number of examples, the amount shows in thousandths of an inch, or fiftieths or hundredths of a millimetre, and is important to know. The earlier design of this tool had a long needle, pivoted close to the end, which contacts with the work, so that a great magnification of movement occurs at the long end, and is seen on a scale. This class, though still made, has been largely supplanted by the more compact and easily read dial gauge, Fig. 57, the hand moving around as the plunger tip is affected. If the contact point is pressed against the work until the hand has made one revolution, it

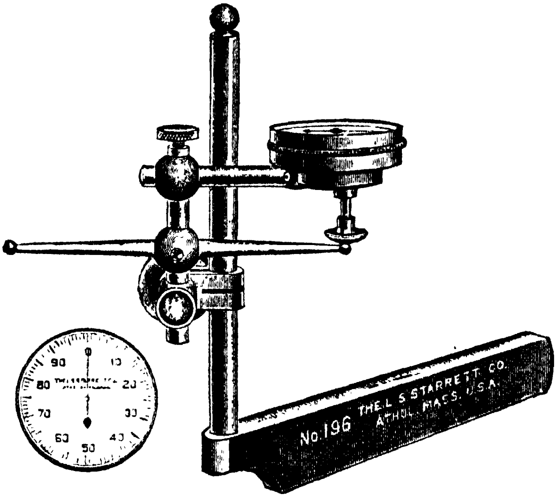


FIG. 58. THE STARRETT UNIVERSAL TEST INDICATOR

will afterwards reveal a plus or minus movement on either side of the 0. A heavy slotted base carries a pillar on which the dial is held with a vertically adjustable arm, such base being moved about similarly to the base of a surface gauge. Sometimes a narrow shank is employed to grip in a lathe tool-post or other tool-holding device, to test parts of machines and work.

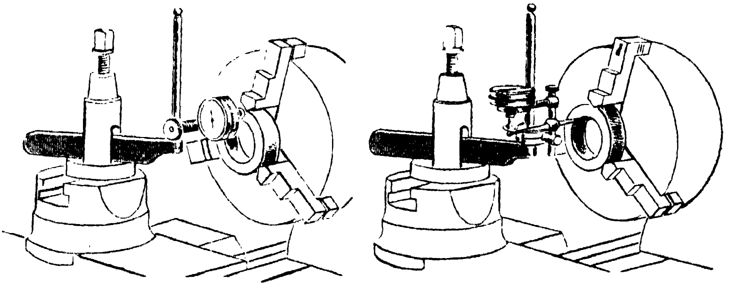


FIG. 59. THE STARRETT INDICATOR MOUNTED FOR LATHE WORK

The dial is also frequently fitted to a small apparatus put on the bench, which rapidly compares components, showing which are above or below the specified size.

A good example of a test indicator is the Starrett instrument illustrated in Figs. 58 and 59, which may be used for all kinds of work. This indicator is simple, reliable, easily read, and very sensitive. The slightest pressure upon the contact point produces a movement of the hand on the dial. The circumference of the dial is divided into 100 equal spaces, each one representing a movement of the contact point of $\frac{1}{1000}$th of an inch. One revolution of the hand therefore indicates $\frac{1}{10}$ in., the capacity of the instrument being $\frac{2}{10}$ths. By bringing the contact point against the work with just enough pressure to give the hand one full turn, then setting it at 0, an opportunity is given for one full revolution of the hand to both right and left of 0, showing a rise or drop in the work and the amount of variation.

SECTION III

DRAWING AND SKETCHING

BY

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SECTION III

DRAWING AND SKETCHING

THE title of this section will suggest that its aim is to show how a mechanical drawing is prepared for use in the engineering workshop, or expressed in more general, but less technical, language: "How to make a working drawing."

It makes no pretence to a consideration of the principles of machine construction or design, each of which is a subsequent consideration.

Mechanical drawing may be described as the engineer's language, for a good drawing correctly detailed will tell clearly all that is necessary concerning the subject of which it speaks, yet without repetition, and in such a manner that it is easily understood.

Our aim now being to understand and to speak that language, we must be thoroughly conversant with its alphabet, which is one of lines instead of letters, each line giving information by its formation, position, and, generally, by its length.

The types of lines which are used when making drawings are few in number, as will be seen by referring to Fig. 1.

The continuous lines (*a*) which form the outline, or edges which are seen when viewing the object from a certain position, should be firm and clean and the most conspicuous of all lines appearing on the finished drawing, all other lines being less pronounced, but none the less clean.

It will be noticed that the abbreviation ℄, for centre line, has been shown in Fig. 1 (*b*). When making a drawing of a certain detail we do not signify *its* centre line by affixing this abbreviation, but it is sometimes necessary to show attached to that detail a component part. This added part is known as "false-work," and is indicated as such by a short dash-dot outline. It is customary then to indicate the centre line of this false work by stating "℄ of - - - - - - - - - -."

When preparing a drawing other lines are used in addition to those shown in Fig. 1, these being termed construction lines, and are used only for our own guidance. They are faint continuous lines, none of which, however, will figure as such on the finished drawing, as the majority of them will then have been lined-in as outline, and the remainder erased.

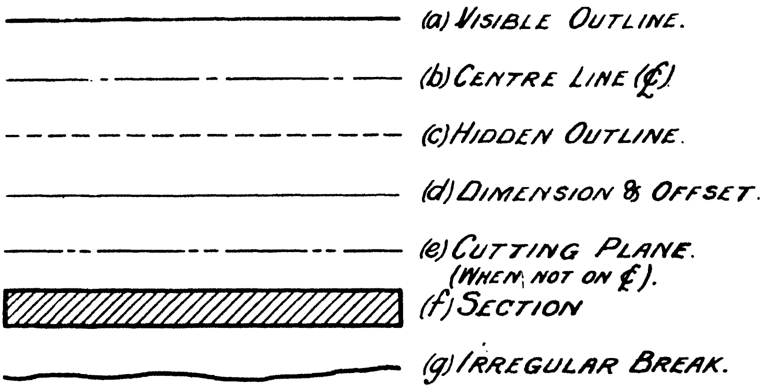


Fig. 1. Types of Lines Used in Drawing

It is sometimes, though seldom, necessary to "ink-in" a drawing, in which case the dimension lines are often shown in blue ink, the dimensions and arrow heads in black, and centre lines as continuous lines in brown (this being preferable to red for photographic purposes).

Drawing Instruments. Reliable instruments can be obtained from drawing office equipment stores, but always remember that good instruments are necessary to make good drawings.

Scales. It is not practicable always to draw an object to its full size, but our representation of it must be such that it is proportionate in all its dimensions if we are to convey a true impression of its shape.

To accomplish this, all the dimensions on our drawing are proportionately reduced to a convenient size, which we can do by letting, say, $\frac{1}{2}$ in. on our drawing represent 1 in. on the object. The drawing is then said to be drawn to a scale of 6 in. = 1 ft., or $\frac{1}{2}$ full size. Again, if we take $\frac{1}{8}$ in. to represent 1 in. on the object, then $1\frac{1}{2}$ in. on our drawing will measure 1 ft. on the object, in which case the drawing is said to be to a scale of $1\frac{1}{2}$ in. = 1 ft., or $\frac{1}{8}$ full size.

Similarly, small details may be drawn to a scale two or three times full size. The scales most frequently used are: Full, $\frac{1}{2}$, $\frac{1}{4}$, and $\frac{1}{8}$ full size. A serviceable scale is one made of boxwood, 12 in. long and of oval section. These are usually graduated to give four different scales on each side, those on one side being: Full, $\frac{1}{2}$, $\frac{1}{4}$, and $\frac{1}{8}$ full size, and on the reverse side: 3, $1\frac{1}{2}$, $\frac{3}{4}$, and $\frac{3}{8}$ full size. Some scales are graduated to give only one scale per edge per side, that is, four in all, and they have the advantage that confusion of scale is eliminated.

It will be noticed by referring to Fig. 2 that the zero mark is not coincident with the first mark on the scale, the reason being that the first whole division is subdivided to give the fractions to the left of 0, the whole numbers given to the right of it, the measurement of a mixed number thereby becoming a direct reading.

When using the scale, place it on the drawing and mark off on the drawing the required dimension to the appropriate scale. The graduations extend, or should extend, to the edge of the scale for this purpose of direct measurement.

The dimension figure which is given on the drawing is, of course, the actual measurement on the object, even though we may have represented it to a modified length.

The manner in which a scale is graduated should receive our attention. It will be noticed that in Fig. 2, the subdivisions are in $\frac{1}{8}$ths, which again are subdivided if the size of the scale permits. A scale graduated in this manner is the most useful form for our use in mechanical drawing, as the general practice in engineering workshops is to adopt multiples of $\frac{1}{64}$ths of 1 in. to give the requisite fractions.

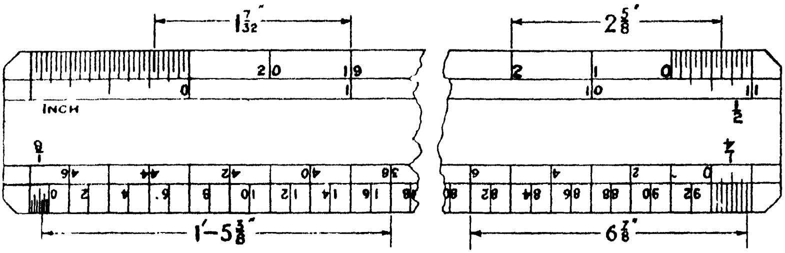


FIG. 2. SHOWING HOW A SCALE IS GRADUATED

Many scales have these subdivisions in $\frac{1}{12}$ths, and are more useful when working in feet and inches to a reduced size, each of the subdivisions then representing 1 in. to the scale adopted.

Others again are divided in $\frac{1}{10}$ths for decimal reading, each subdivision then expressing 0·1 to the scale in use.

Pencils for all mechanical drawings should be sharpened to a chisel point and kept to a sharp edge, especially when lining-in, by lightly rubbing on a smooth file, or strip of glass paper or emery cloth.

For sketching and dimensions a round point should be used. No definite rule can be given as to the correct grade of pencil to use, as this will depend to a very great extent upon the lightness of touch of the draughtsman, but as a general guide it is suggested that a grade H be used for construction lines, and an HH for lining-in.

When sharpening a pencil for drawing purposes always let the point be made on the end remote from that on which the grade is expressed.

Ink is used mostly, of course, for tracing purposes, but will be required if a drawing has to be inked-in. It is best to procure this already mixed, as it is sold in conveniently small bottles as Fixed Indian Ink. This, together with any coloured inks which are used, should be waterproof, as the drawing when inked-in might have to be coloured.

DIMENSIONS AND DIMENSIONING

The mechanic when working to a drawing should adhere to the dimensions which are given thereon, and should never have occasion to place his rule, or any other tool, on the drawing. For this reason there are many points to be observed in the dimensioning of a drawing, the chief of these being—

1. Give all the necessary dimensions, but do not repeat them unnecessarily.

2. Do not leave the mechanic to make a lot of calculations before he arrives at the dimension he wants.

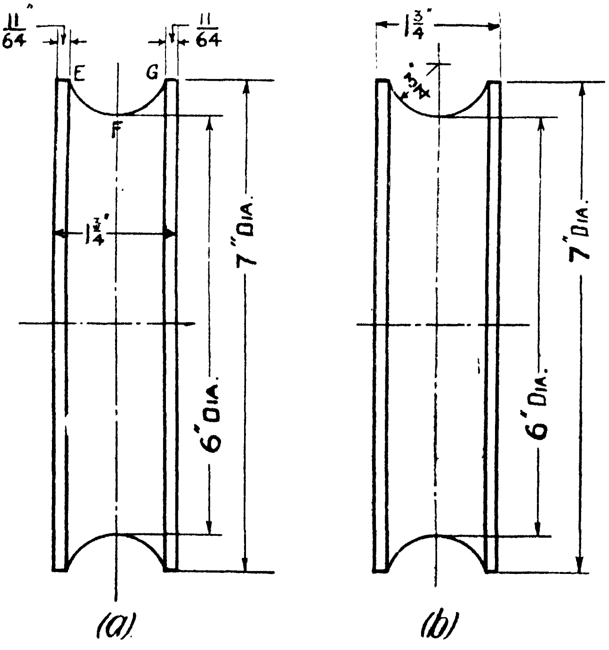
3. The dimensions given must be right, and should therefore be checked before the drawing is issued.

4. The dimensions should be those which are required by the mechanic on the job.

In Fig. 3, two different ways of dimensioning a sheave are shown at (*a*) and (*b*). The dimensions given at (*a*) might be exact numerically, but are not those required by the mechanic on the job, who when finishing the groove will require a radius tool, and must therefore determine what radius will just touch points

E, *F*, and *G*. Now if we have drawn it correctly we have found that radius, and should give it accordingly as shown at (*b*).

A very good rule to adopt is to dimension the drawing as if you had to work to it.



(a) (b)

FIG. 3. INCORRECT AND CORRECT METHODS OF DIMENSIONING

5. Dimension to ℄s, but never on them. A ℄ is sometimes required to serve the dual purpose of ℄ and cutting plane, in which case it is still shown as a ℄, but it should never be used as a dimension line.

6. Place the dimension in a break in the dimension line, and at right angles to it. The arrow heads at the ends of the dimension line should be kept of uniform size, as neat as possible, and touching but not

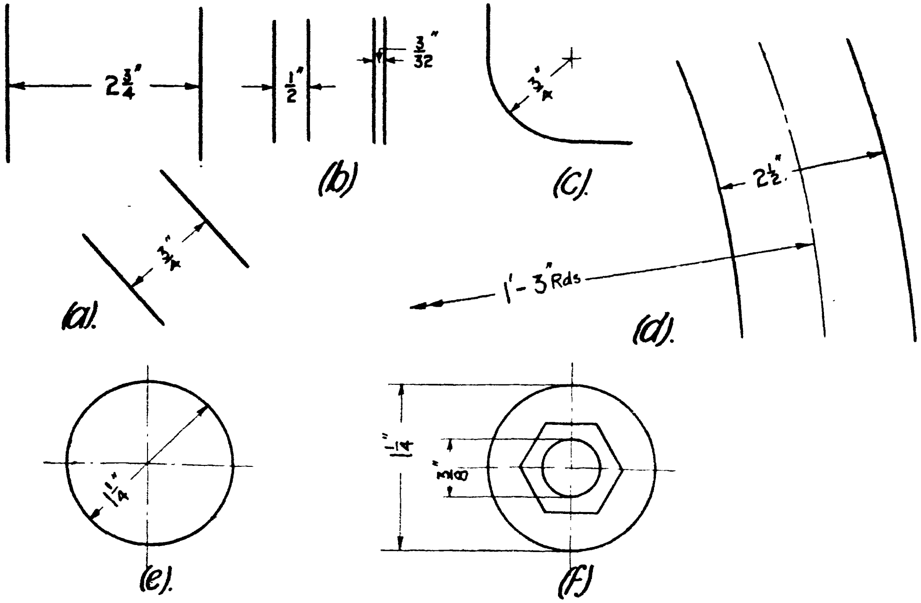


FIG. 4. STANDARD METHODS OF DIMENSIONING

overlapping the lines to which the dimension applies (see Fig. 4).

Dimensions for small measurements may be given as shown at Fig. 4 (*b*), whilst those for radii should have the centre from which they are struck indicated as shown at (*c*), unless the centre is very remote, in which case it is given as shown at (*d*), the two arrow heads together indicating that the centre is situate on that line produced.

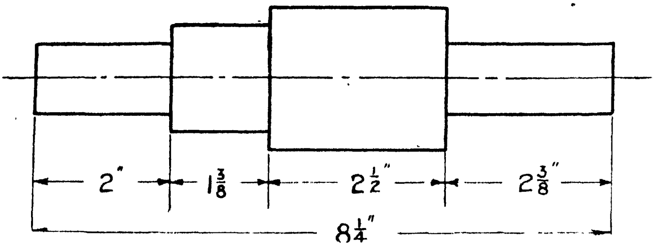


FIG. 5. SHOWING A CASE WHERE DUAL DIMENSIONING IS REQUIRED

The diameter of a circle may be given as shown at (*e*) or (*f*). If considerable detail is contained within the circle, it is preferable to dimension to offset lines as shown at (*f*). When shown as at (*e*) do not print DIA. after the dimension. If the dimension line passes through the centre, and terminates at the circumference, it cannot be anything but a diameter.

7. When an overall dimension is the sum of individual dimensions, keep the latter lineable as shown in Fig. 5. This is conducive to neatness and prevents " dimension-hunting."

8. Plain figures should be used for dimensions as shown in Fig. 6. When giving a fraction, the line separating numerator and denominator is kept parallel to the dimension line.

9. Feet and inches are denoted by ′ and ″ respectively. If a detail is, say, 6 ft. long exactly, when

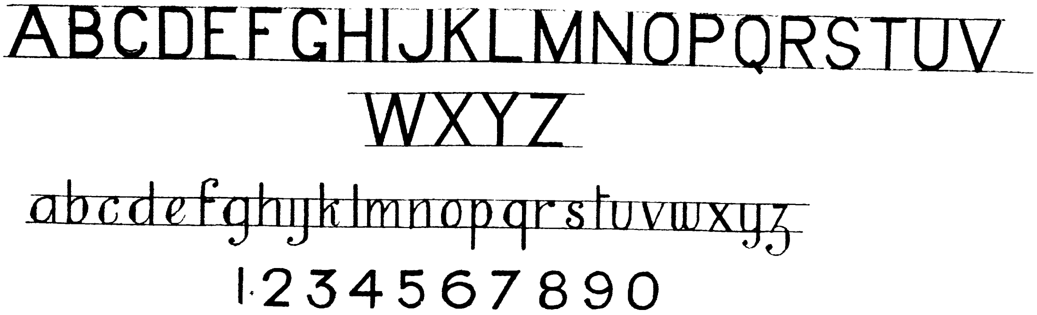


FIG. 6. STANDARD LETTERING AND FIGURING EMPLOYED BY THE DRAUGHTSMAN

dimensioning it add a cypher for the inches, so that the dimension would appear 6′–0″, a short dash separating feet and inches.

The lettering which is used on drawings of a mechanical nature is kept severely plain, the type to be used generally depending upon the firm's practice.

Many firms insist on the use of plain block type throughout, whilst others reserve the block type for titles, and use the small type for such notes as may be necessary on a drawing.

ORTHOGRAPHIC PROJECTION

In order to make a working drawing, we must now study the method by which solid bodies, i.e. bodies having length, height, and width, may be represented in order that their true size and shape shall be accurately described.

This is effected by viewing the body in two or more directions, these directions being at right angles to one another. It is obvious that two such views at least are necessary, even for simple bodies, if a correct representation of the three dimensions is to be given.

Let us suppose, for example, that a V-block rests with its base on a sheet of paper placed on a marking-off slab, the paper being cut along the lines *EG* and *HF*, and creased for folding along the lines *GH*, *KG*, and *LH*. If we look vertically downwards on this, we shall see that which is shown in Fig. 7 (*A*), known as a PLAN. Now fold the paper about the crease lines *GH*, *KG*, and *LH*, in such a way that the three planes so formed are at right angles to the horizontal plane, and the angle contained by any two is a right angle. We have now four planes, three being vertical and one horizontal. The points *A*, *K*, *L*, and *D* are now vertically above points *E*, *G*, *H*, and *F* respectively,

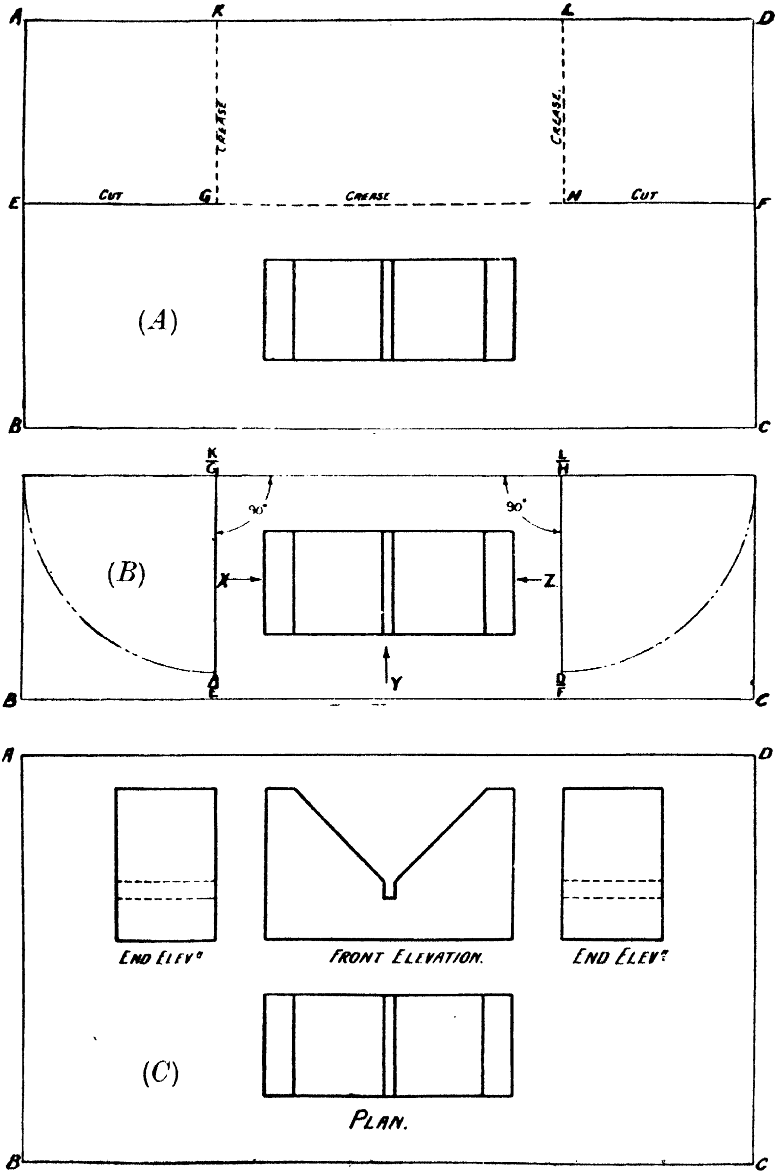


Fig. 7. Illustrating the Principle of Orthographic Projection

and the vertical edges have accordingly been lettered $\frac{A}{E}$, $\frac{K}{G}$, $\frac{L}{H}$, and $\frac{D}{F}$ in Fig. 7 (*B*).

Now let us view the V-block from the front, that is, in the direction of the arrow *Y*. In "viewing" a body in the drawing sense, we do not keep in one position, but work from top to bottom, and from side to side of the object, in order that our line of vision is kept always at right angles to the plane upon which we are recording our view. The lines of vision are more generally called *projectors*, and the planes upon which we record our views are termed *planes of projection*. It must therefore be remembered that the projectors must always be kept at right angles to the planes of projection. Then returning to the view in direction of arrow *Y*, Fig. 7 (*B*), if we project our view on to the plane directly behind the V-block, that is, plane $\frac{K}{G}$, $\frac{L}{H}$, we shall obtain what is known as a FRONT ELEVATION.

The elevation will therefore express the outline of a vertical face, giving lengths and heights; the plan will express the shape of outline of horizontal faces, giving lengths and widths.

Now let us obtain END ELEVATIONS by viewing the V-block on its end faces, i.e. in directions of arrows *X* and *Z*, and we shall obtain rectangles which express the height and width. The edges of the groove cut through the block at the bottom of the V are not seen in the end elevations, and are therefore shown dotted.

Now if we return our paper to its original horizontal position, thus bringing all our views in to one plane, our drawing will appear as shown in Fig. 7 (*C*).

Another view which is sometimes desirable is one which shows the under side of an object, and which is termed an INVERTED PLAN.

A plan being a view looking vertically downwards, it is reasonably obvious that an inverted plan must be a view looking vertically upwards, wherefore the plane of projection will be above the front elevation.

If the foregoing procedure has been understood, and the fact that projectors are kept always at right angles to the plane of projection is remembered, then we shall recognize that in projecting one view from another we *carry forward* all that is seen and place it on the end remote from the point of vision. The disposition of our views therefore becomes—

	Inverted Plan (Viewed from front elevation vertically upwards)	
End Elevation (Viewed horizontally from right-hand end of front elevation)	Front Elevation (Viewed directly in front of object)	End Elevation (Viewed horizontally from left-hand end of front elevation)
	Plan (Viewed from front elevation vertically downwards)	

It is seldom that all these views are required to define one object, and we should confine our views to those which are necessary to show full details of the object. In the example of the V-block, the end elevations do not furnish information further to that given in the plan and front elevation, and for purposes of drawing should be dispensed with as unnecessary views.

DRAWING TO SCALE

Now let us draw the plan and elevation of an octagonal prism 6 in. high and 3⅞ in. across the flats, when it stands on one of its ends with two of its faces parallel to the vertical plane.

First choose the scale to which we will draw the required views, say, half full size, then set out the ℄s. Using the intersection of these in plan as a centre, set out a circle 3⅞ in. diameter, as a construction circle.

Next we have to place an octagon around this circle, each side being a tangent to it. At the centre of the circle we have four right angles or 360 degrees, therefore if we divide 360 degrees by the number of sides the figure contains, we shall obtain the points on the circumference at which we must draw the tangents to form the sides of the figure.

On dividing 360 degrees by 8 we get 45 degrees, therefore four of our points will be at the intersection of the ℄s with the circumference, the remaining four being on the circumference midway between them, or at 45 degrees to each ℄. We have now obtained points *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*.

Using the T-square for the horizontal lines, and the vertical edge of the set-square for the vertical lines, construct a square around the circle, making each side touch, but not cut, the circle points *a*, *c*, *e*, and *g*.

Then, by using the 45 degree set-square, place another square around the circle at points *b*, *d*, *f*, and *h*, each side again being a tangent to the construction circle.

We now have two squares, each being $3\frac{7}{8}$ in. across the flats, one square being set at 45 degrees to the other.

Next fix the height of the prism (6 in.) in elevation. The distance between plan and elevation, and indeed between any two adjacent views, is of no importance, but we want to place the views in such a manner that whilst projection is easily made from one to the other, they must be far enough apart to keep them distinct and to avoid interference.

Looking on the front of the prism, we shall see four of the edges, *D*, *E*, *F*, and *G*, extending the full height of it, the remaining four being directly behind those which are visible.

We can now erase the construction circle in plan, and line-in the whole drawing, after which any other construction lines which remain must be erased.

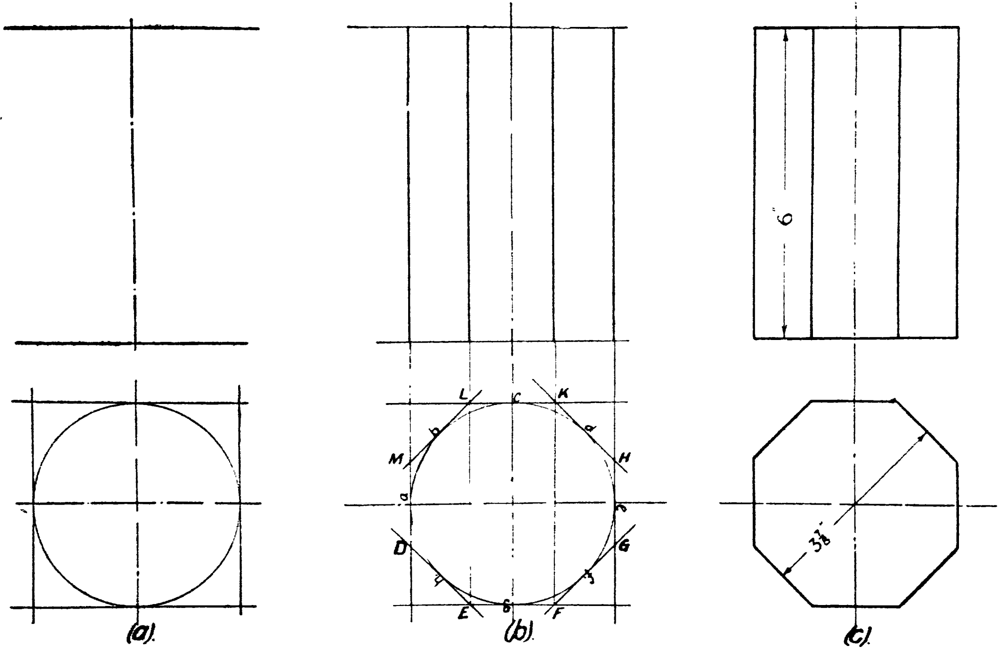


FIG. 8. THREE PHASES IN THE DRAWING OF AN OCTAGONAL PRISM

The plan and elevation will then appear as shown in Fig. 8 (*c*).

SECTIONS

It is often necessary to show an internal detail of an object. If it is of comparatively simple formation, it can be adequately represented as hidden work, and therefore shown dotted, but in more complicated cases it should be exposed to view by "taking a section" by a cutting plane, the position of which may be selected at will, but in such a manner that maximum exposure is given to the portions which we wish to illustrate.

For this purpose, the cutting plane is usually coincident with the centre line of the inner detail. In taking a section through an object, it will be simplified if we imagine that we have actually sawn through the object, keeping the saw blade on the cutting plane during the entire process. When completely through, remove that part nearest to us which had been obstructing our view of the interior, and we shall see that detail which we selected by the position of our cutting plane. The solid portions through which we have sawn are then hatched on the surfaces cut as shown in Fig. 1 (*f*).

Many beginners experience difficulty in deciding the boundaries which enclose this hatching, and at best cannot claim confidence that what they have shown is right. This matter will be comparatively simple if we recognize the fact that when sawing through a substance (which we have already imagined we have done) the saw will leave tooth marks on the surface on which it has cut, and we can therefore liken the hatching to surface marks due to the saw teeth.

The former practice of indicating the materials of construction by different forms of hatching has now been almost entirely superseded by the less tedious method of using fine continuous lines sloping at

45 degrees (Fig. 1 (*f*)), the materials of which the various details are made being stated in the schedule of parts included on the drawing, and which we will consider later.

Concrete and wood, however, still have their respective sections, which are as shown in Fig. 9.

Examples of sections will be numerous as we proceed with the drawings, and will be dealt with as they occur.

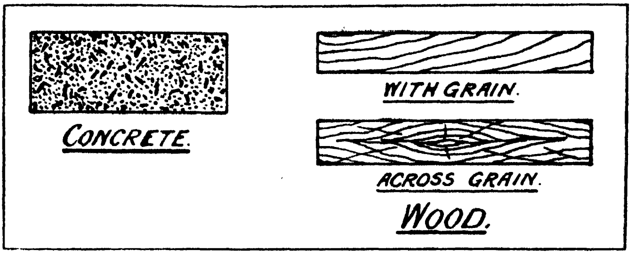


FIG. 9. CONVENTIONAL METHODS OF INDICATING MATERIALS

BREAKS

When detailing a long piece of metal, no useful purpose is served by showing its full length to scale. To do so would mean that a greatly reduced scale would necessarily be adopted, and any details which the piece carried must be, of course, to the same small scale, which, if not impracticable, is bad practice, as our drawing has to be read and worked to.

It is usual to draw it to a scale chosen so that its smallest detail can be conveniently dimensioned and read, this scale being used for all dimensions except the length which is shown "broken." By this we imagine that a portion of its plain length has been removed, and indicate this by irregular boundaries, which for ease in reading should indicate the section of the bar. Typical examples of breaks are shown in Fig. 10. The break must occur at some point between the ends, and must not remove either of them, as we have to give the full length dimension which, of course, necessitates showing both ends.

When showing a break in a tapering length, we must

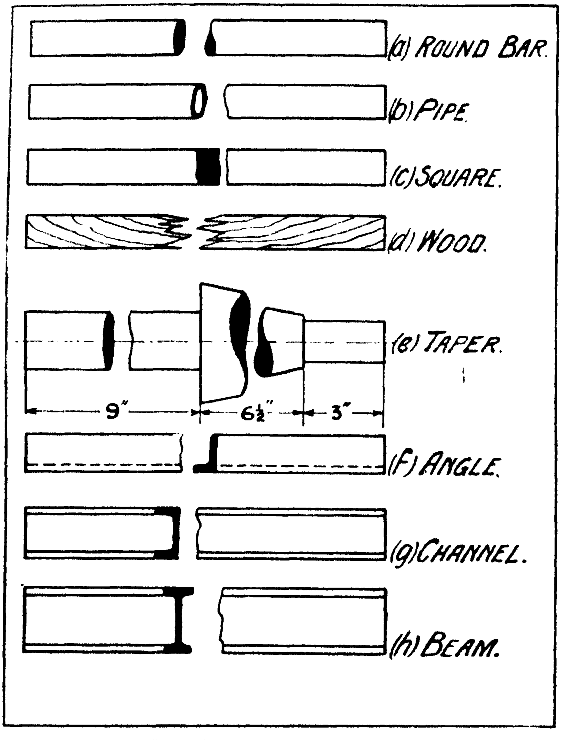


FIG. 10. THE REPRESENTATION OF BREAKS

not overlook the fact that one end of the removed portion will be of greater section than the other, and will therefore appear as shown in Fig. 10 (*e*).

The elevations of the channel, and beam, show two lines for each flange, but strictly speaking this is not correct; only the outside lines, which denote the depth, are shown if the rules of projection are truly observed.

The inner faces of the flanges taper outwards, 2½ degrees in the case of the channel, and 8 degrees in that of the beam, and these tapers merge into the widths of the flanges and webs with a radius, and therefore no sharp edges are visible. It is customary, however, to introduce the inner line to represent the flange thicknesses.

TO DRAW A HEXAGONAL PRISM

We will consider now the plan and elevation of an hexagonal prism, 6 in. long, 3 in. across the flats, standing on one of its ends.

The method of construction of the plan and elevation is similar to that of the octagonal prism previously considered, with the exception that in order to obtain the plan, the angle of inclination to one of the ℄s will be 360 degrees divided by 6, it being a 6-sided figure, which gives us 60 degrees.

The plan and elevation will then appear as shown in Fig. 11 (*a*). Now let us assume that a hole 2 in. in diameter has been drilled through the prism. This will mean that the plan now includes a circle 2 in. in diameter, which projected on the front elevation will give two dotted lines (as they are hidden in this view), each line being 1 in. distant from the ℄.

Suppose the prism be cut by a cutting plane *PQ*, inclined to the base of the prism at an angle of 60 degrees, as shown in Fig. 11 (*b*).

The imagined effect of this cutting plane is to remove entirely the whole of the portion above it, which leaves us with a figure as shown in the front elevation of Fig. 11 (*c*), but it will not have caused any modification to the plan.

This latter statement may not at first be apparent, but it will be less confusing if we remember that a plan is always obtained by viewing a body *vertically* downwards, and cannot express differences in height.

Let us now project an end elevation looking in the direction of the arrow X. In doing this, and indeed whenever an end elevation is being added, do not overlook the value of the plan, for in viewing this in conjunction with the elevation in the direction indicated, it will be seen that edges $\frac{G_1}{H}$, $\frac{K_1}{L}$, and $\frac{M_1}{N}$ are directly behind and of heights equal to $\frac{E_1}{F}$, $\frac{A_1}{B}$, and $\frac{C_1}{D}$ respectively, therefore putting our projectors across from points E_1, A_1, and C_1 we shall determine the heights of these points together with those of points G_1, K_1, and M_1.

From the plan we can obtain the distances of the edges $\frac{E_1}{F}$, $\frac{A_1}{B}$, and $\frac{C_1}{D}$ from the ℄ ST, the distances of edges $\frac{G_1}{H}$, $\frac{K_1}{L}$, and $\frac{M_1}{N}$ being, of course, the same respectively. Taking these distances in our compass we can place them on either side of the ℄ on their appropriate projectors, and so locate their respective positions in the end elevation.

Joining these points we shall obtain the figure shown. Next to project the shape of the hole. Let us take any number of points on the slant surface between the dotted lines representing the hole in elevation. For this purpose select at random points 1 to 12, and carry projectors across from these points to the end elevation.

We have now to determine the widths of the hole at each of these points. Let us take point 5 for instance, the width of the hole at that point can be obtained from the plan by dropping a perpendicular from the point to the hole in plan, and measuring by our compass the distance of the edges of the hole from the ℄. Taking this distance, transfer it on the projector of point 5 on

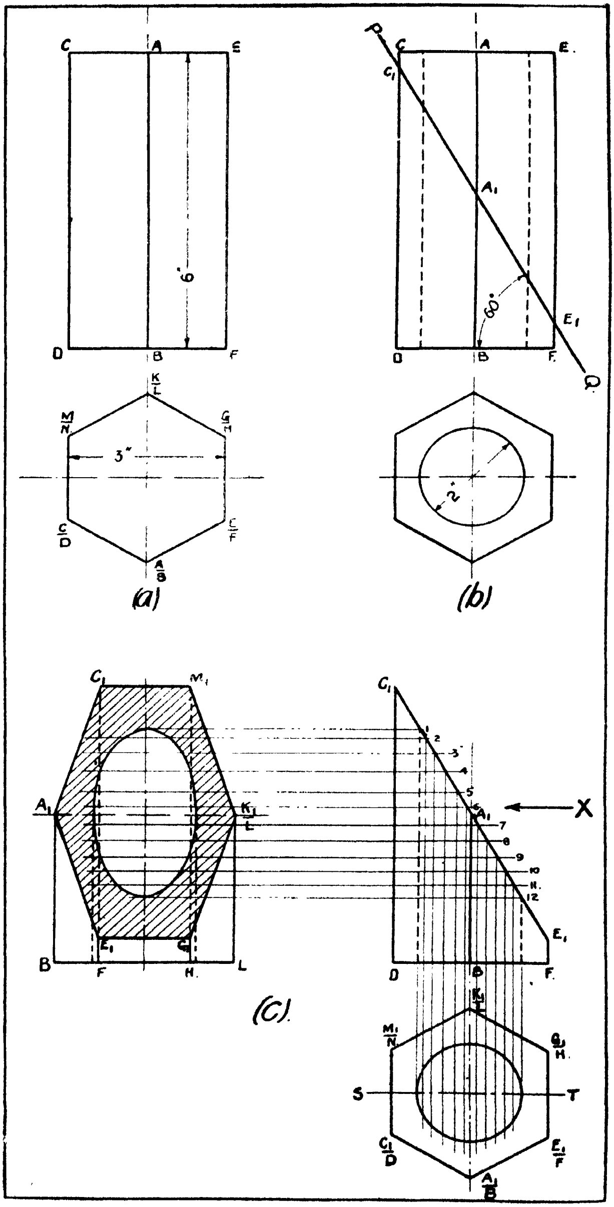


FIG. 11. STAGES IN THE DRAWING OF A HEXAGONAL PRISM

both sides of the ℄ in end elevation. Repeating this for each point 1 to 12 and joining the points so found, we shall obtain the true shape of the hole when viewed in direction of arrow *X*.

It should be noted that the width of the hole on the ℄ is, of course, equal to its diameter, viz., 2 in.

It is important to realize that the method adopted for finding the shape of this hole in the end elevation is applicable to a section taken at any angle through any circular body.

When dealing with sections it was stated that when we assumed we had cut through a solid substance, we indicated this by hatching the surface upon which we had cut, and we therefore hatch the surface as shown in the end elevation, the hole not being hatched, as we have not encountered any substance.

We may now complete the views by lining in those edges of the prism which are visible.

SCREW THREADS

A point which travels around a cylinder, and also along its length at a uniform rate, is said to describe a helix or helical curve.

The edges of all screw threads are therefore helices, for when cutting a thread, the tool travels along the length of the cylinder while the latter is rotating, therefore any point on the cutting edge of the tool produces a helical curve on the cylinder. For each complete revolution of the cylinder, the tool travels an exact length, this length being termed the "Lead." The lead of a screw may therefore be defined as the distance measured in a line parallel with the axis between any point on a thread to a corresponding point on the same thread, after it has travelled once around the cylinder.

This, in effect, is the distance, measured axially, which a nut will travel along the screw in one complete revolution.

When cutting a screw thread, successive cuts produce different helices, for although the lead remains constant we are generating the helix on a different diameter, the reduction in diameter being equal to twice the depth of cut.

It will be understood, then, that the slope of the helix, or helix angle, is more acute at the root of the thread than it is at the crest.

The diameter at the root of the threads is known as the " Core " diameter. The " Pitch " of the threads, which we will call " p," is the distance measured axially between corresponding points on adjacent threads.

It may be thought that the definitions of lead and pitch are identical.

In single-threaded screws they are coincident, and it is customary then to refer to pitch only, but not all screws are single threaded and, for considerations which will arise later, we will do well to recognize and remember the distinction between them.

An example that will emphasize this distinction is the square-threaded screw, which is largely used for transmitting motion. Its name is derived from the shape of the thread when cut by a plane parallel with the axis ; incidentally, on any other plane its section is not a square. As the gap must equal the thread and the section is a square, it follows that the width and depth of the thread must each equal $\frac{p}{2}$, the core diameter thereby becoming the outside diameter less the pitch (p).

A square-threaded screw is often required to impart a rapid motion to its nut, and must therefore have a quick lead. Suppose the diameter of a screw is 1½ in., and the travel of the nut per revolution of the screw, i.e. the lead, is to be 1 in.: if the screw is single threaded the core diameter will be $1\frac{1}{2}$ in. – 1 in. or $\frac{1}{2}$ in., which is obviously inadequate. To obtain a stronger core we must decrease the depth of the thread, which can only be effected by decreasing p. If then, instead of having only one thread in the required lead we place other separate threads, we shall decrease the pitch proportionately and obtain what is known as a multiple-threaded screw. If we make it double threaded (2 starts) we shall halve the original pitch, the core diameter then becoming 1 in.; if we make it quadruple threaded (4 starts), the pitch would be $\frac{1}{4}$ in. and the core diameter $1\frac{1}{4}$ in.

The numerical value of the lead is therefore equal to the sum of the pitches which occur in it. In Fig. 12 the development of a square-threaded screw, 3 in. diameter, $1\frac{1}{2}$ in. lead, 2 starts, is shown, part of it being in section, on which part a nut also in section has been placed. Construction circles representing the full and core diameters have been added at one end, and divided into 12 equal parts by using the 30 degree set-square (360 degrees $\div$ 12 = 30 degrees).

The lead $1\frac{1}{2}$ in. has also been divided into the same number of equal parts. Now from our definition of the helix, when a point has travelled $\frac{1}{4}$ around the cylinder it will have travelled also $\frac{1}{4}$ of the lead, $\frac{1}{2}$ around the cylinder, $\frac{1}{2}$ the lead and so on, wherefore if we project points 0, 1, 2, . . 11 on the circumference to intersect the corresponding lengths on the lead, the points so found will rest on the helix of the thread, this being applicable not only to the crest, but also to the root of the thread. Between points 6 and 12 the helix is on the back of the cylinder, and therefore appears dotted in the front elevation.

As this is a double, or 2 start thread, the pitch will be $\frac{\text{lead}}{2} = \frac{3}{4}$ in., the width and depth of the thread being $\frac{p}{2}$ or $\frac{3}{8}$in. Setting our compass to $\frac{3}{8}$ in., and using the helices which we have obtained as edges of a thread, we can set off this length along each projector on the front elevation, and so obtain helices parallel to those already constructed, for as many threads as required. Lining-in the crests and roots we shall complete the threads of the screw as shown.

This construction is equally applicable to the drawing of a spiral spring of either square or round section.

If now we remove the screw from the nut in section, the screw thread appearing in this half nut will be left-handed (L.H.) as shown, the thread being that portion which engaged the thread on the back of the cylinder.

From the foregoing pages, we may deduce all the necessary features which concern us in the representation of screw threads, whatever the shape of their thread may be. These features are as follows—

1. The edges of screw threads are helices.
2. A right-handed (R.H.) screw slopes downwards from left to right.
3. The thread shown in a tapped hole in section is of the same slope, but of opposite hand to that of its screw, i.e. a R.H. nut in section has its threads sloping upwards from left to right.
4. The representation of the slope of a thread is half its lead in diameter.
5. Lead and pitch are not identical. In single-threaded screws, they have the same value, and it is customary then to refer to *pitch* only; hence the term *lead* is generally limited in use to multiple-threaded screws.
6. Lead = pitch × number of starts.
7. Lead of a screw determines the rate of advancement of its nut, whilst the pitch determines the proportions of its threads.

8. In all screws having an odd number of starts, i.e. single, 3, etc., a gap will be directly opposite a thread on diameter; in even starts, 2, 4, etc., crests of threads will be directly opposite.

9. When dimensioning screw threads, if single threaded, give diameter, threads per inch, and form of thread. If multiple threaded, give diameter, lead, number of starts, and form of threads.

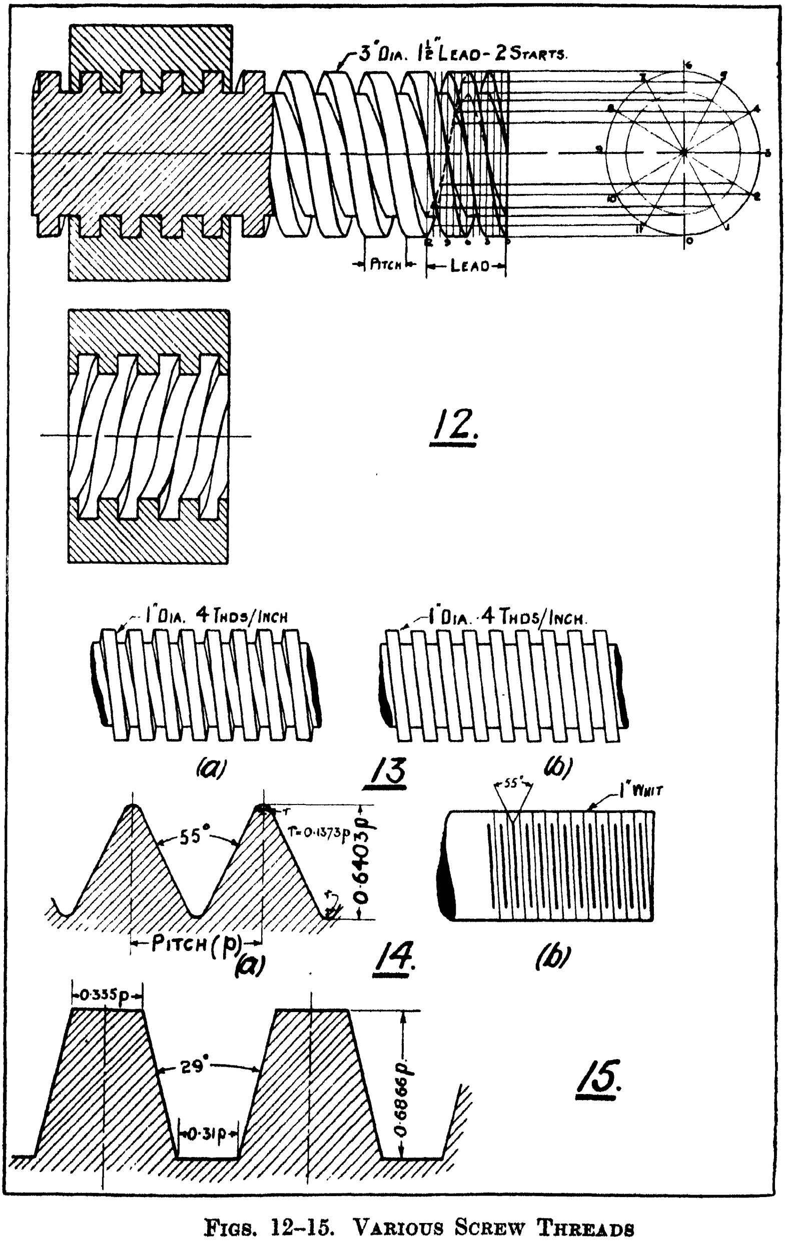
The conventional methods by which square threads are indicated are shown in Fig. 13 (*a*) and (*b*), the curvature of the thread edges being neglected in each case. An approximation is made for the helix angle at the root of the thread in (*a*), whilst at (*b*) it is omitted altogether.

The form of screw thread with which we will have to deal most frequently is the V thread of Whitworth form, the proportions of which are shown in Fig. 14 (*a*), this being the form of screw usually adopted for screwed fastenings.

The pitch of the British Standard Whitworth (B.S.W.) thread has been standardized with regard to the diameter of the bar on which it is cut, e.g. 1 in. diameter Whitworth (or B.S.W.) has 8 threads per inch or $\frac{1}{8}$ in. pitch, $\frac{3}{4}$ B.S.W. has 10 threads per inch or $\frac{1}{10}$ in. pitch.

For certain purposes, when a finer adjustment or a stronger core is desirable, the British Standard Fine (B.S.F.) thread is adopted. This also is of Whitworth form of thread, but for corresponding diameters has more threads per inch than the B.S.W., and therefore a smaller pitch.

When threading a pipe, its thickness necessitates a shallow thread, and to meet this requirement another standard exists, and is known as the British Standard Pipe (B.S.P.) thread. This again is of Whitworth form, but unlike the B.S.W. or B.S.F. is not designated by



Figs. 12–15. Various Screw Threads

the diameter over the crests of its threads, but by the bore of the pipe. The crest diameter is a decimal one, and slightly less than the external diameter of the pipe. This thread, although standardized primarily for screwed pipe connections, is by no means limited in use to pipe work. Generally speaking, the designer will use a standardized thread which is appropriate to his requirements.

There are other forms of V threads with which we should be acquainted, but which are not of Whitworth form. The United States Standard (U.S.S.) thread, sometimes called the Sellers thread, has flat crests and roots, the widths of these being the same, and equal to $\frac{p}{8}$. The depth of the thread $= 0{\cdot}6495p$, and the angle contained by the walls of the thread is 60 degrees.

The British Association (B.A.) thread is confined to small screws, and is of metric measurement. It is designated, not by diameter, but by numbers, the largest being No. 0 of 6 mm. diameter and 1 mm. pitch, and the smallest No. 25, of 0·25 mm. diameter and 0·072 mm. pitch. The angle contained by the slant sides of the thread is $47\frac{1}{2}$ degrees, the depth of thread $0{\cdot}6p$, and the radius at the root and crest $\frac{2p}{11}$.

The proportions of a worm thread are shown in Fig. 15, and these again are dependent upon the pitch. The pitch is this case must, of course, be exactly equal to the circular pitch of its engaging wheel. The width of the gap at the root is less than the width of the crest of the thread, because of the clearance which is allowed for the crests of teeth in the wheel.

Many other forms of threads exist, but we will confine our attention to those which have been given, as they are the forms of threads which are most likely to occur in our drawings.

The conventional method by which V threads are indicated is shown in Fig. 14 (*b*). It will be noted that the V is omitted entirely, and that a thin line represents the crest and a thick line the root of the thread.

This is a convenient and quick method of representing a screw thread, but we must not take that to mean that it can be a careless one also.

The lines representing the crests should be spaced approximately to scale, and be of the appropriate slope. The core diameter may be approximately gauged by using the reverse sides of the 60 degree set-square, and, setting its edge to the crests of adjacent threads, drawing lines to intersect at a point which will be approximately on the core diameter.

Reproducing this by our compass on to the other side of the ℄ we may draw parallel construction lines through these points to give guide lines for those representing the roots of the thread.

Another method, which however is not general practice, is to omit the slant lines representing the roots and crest, and simply line-in the one which we have used as a construction line to guide us for the thick root lines. The lines so drawn indicate the depth of the thread, and, as far as the drawing is concerned, is the only indication that the portion shown in that manner is screwed.

It is good practice to adopt this latter method to represent a tapped hole, or the screwed length of a stud, or other fastening, in a detail not shown in section. It will, of course, be shown dotted, and the two parallel lines indicating the core diameter will extend the full length of the screwed part.

SKETCHING

Sketching is usually adopted for one of three purposes—

(*a*) For small jobs in the workshop, for which the services of the drawing office would not be required.

(*b*) For obtaining particulars of existing machinery or site.

(*c*) For expressing an original idea or to give mechanical expression to verbal instructions.

The purpose for which a sketch is required does not sensibly affect the method of its production, for a sketch is, or should be, a drawing prepared freehand with due regard to all the laws which govern the production of a mechanical drawing. The most frequent use of sketching is that applied for purpose (*b*), this being one of the duties of a fully qualified draughtsman, who will often experience more anxiety with his sketching, than he does with his finished drawing. It may be that details of a piece of machinery are required for purposes of renewal or modification, or that particulars of local conditions are required for the installation of new plant. He must obtain these particulars in their entirety, and must satisfy himself that his sketches are such that all necessary dimensions and particulars are contained therein which will enable working drawings to be prepared from them, either by himself or by another draughtsman. This should be accomplished by the one visit to the site, as frequent visits to the site will inevitably be taken as a sign of incompetence; indeed it frequently happens that further opportunity for obtaining forgotten dimensions is not available.

If the purpose of his visit to a site is to obtain particulars for the installation of machinery or plant, it is not enough to ascertain that the requisite floor space and head-room are available, but he must view the surrounding conditions so as to determine how the plant is to be brought to the site, and what parts, if any, must be assembled on site. He may have also to arrange for certain drives, and must therefore utilize any facilities which the site offers so as to combine economy with efficiency. To attain the proficiency necessary to meet these requirements it is good practice to sketch parts of dismantled machinery, seeking to obtain all particulars of them before they are reassembled and inaccessible for further measurement, then make a working drawing from them.

The type of sketching for purpose (*c*) is necessarily somewhat crude in its first stage, inasmuch as it is a matter of design, and as such must be viewed only as a graphical representation of an idea, which has to be developed in stages.

Further comment upon this type of sketch is unnecessary, as we are not particularly interested in it at present.

The type with which we are directly concerned at this stage is that given at (*a*), and which is usually applied to an object having few dimensions.

This sketch should be reasonably to scale, and to effect this the use of squared paper will be found of great advantage, as each square can be taken to represent a unit length, the lines on the paper may be used as projectors and lines on the drawing, and the right angles given by the squares will keep our sketch square.

A sketch for tool-holder is shown in Fig. 16. In the front elevation, the lines *g* and *h* are edges which can only be formed by the portions *B* and *D* being of greater or lesser thickness than the portion *C*. The sectional plan and end elevation make it clear that they are less. The absence of a similar line between *A* and *B*, and between *A* and *D*, would tend to show that they are of equal thickness, but from this view it is not definitely certain that they are, for if a regular taper obtained from *hg* to *ef*, no alteration would be effected in this view, as there would not be any sharp edges. The remaining views, however, make it clear that *A*, *B*, and *D* are of equal thickness. The edges *e* and *f*, which are formed by the chamfers meeting the face of *A*, extend the full width of *A*, and will be seen accordingly as shown at *e* and *f* in the end elevation. The edges *b* and *d*, between which space is provided to accommodate the tool, will not be visible when viewed on the end of *A*, and are therefore shown dotted in the end elevation.

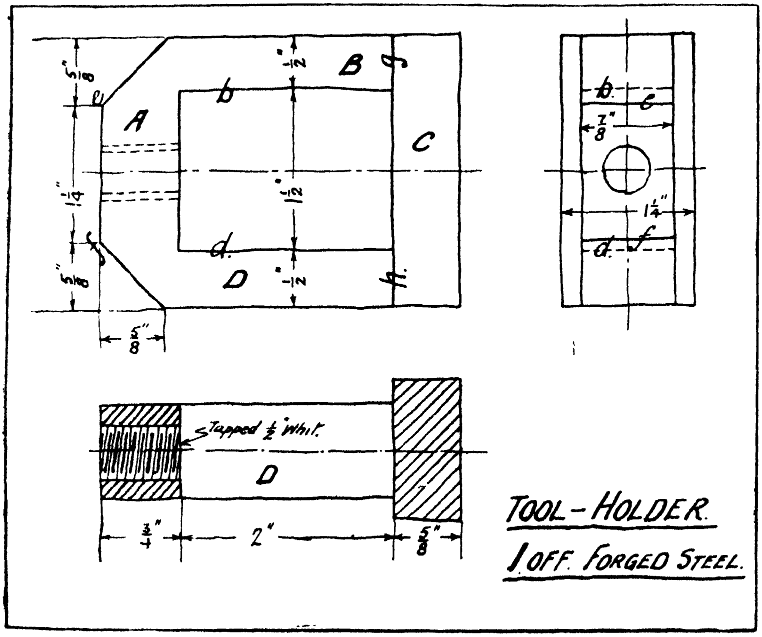


Fig. 16. Rough Sketch of a Tool-holder

The sectional plan has been taken by a cutting plane on the ℄ of the front elevation, by which the entire top half of that view has been removed. Looking vertically downwards on the remaining half, we shall obtain the sectional plan shown, the thread in the tapped hole

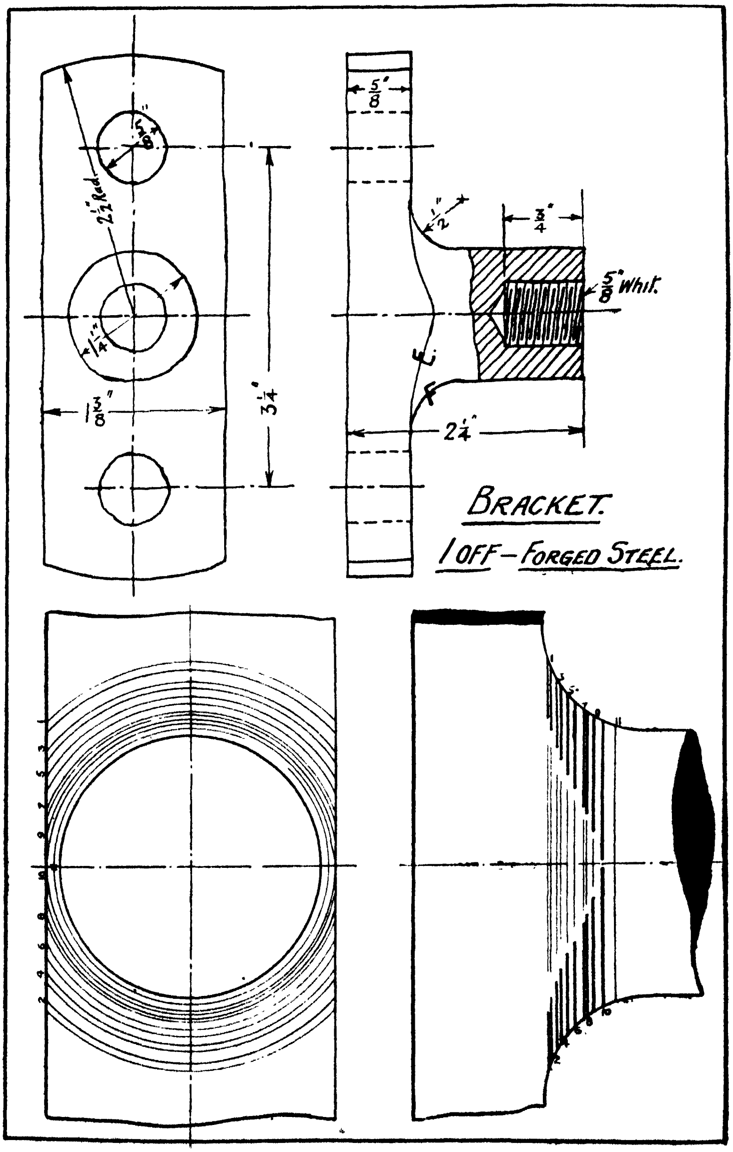


Fig. 17. Sketch of a Bracket

being shown left-handed, thus indicating that the locking screw has a right-handed thread.

As the object is one piece of metal throughout, the section lining is kept at the same slope on those surfaces on which we have cut by our cutting plane.

A sketch of a bracket is given in Fig. 17. The general outline of this is obtained by simple projection, and should now be followed with little difficulty. The lug has been broken to expose the tapped hole. It will be noticed that a V occurs at the bottom of this hole, and is formed, of course, by the point of the drill. Its slant sides are shown to rise to the core diameter, this being the diameter of the tapping drill used, but it is more usual, though less correct, to draw these rising to the full diameter of the thread. A very close approximation is given for these slant sides by using the 60 degree set-square, thus obtaining a contained angle of 120 degrees instead of the true angle of 118 degrees.

The curve *E* is formed automatically by the intersection of a flat surface and a radius. In our drawings, this and similar instances will frequently occur, and for this reason we should understand how the shape of this curve is found. We shall then be able, with a little thought, to apply the construction to similar intersections. Let us suppose that the radius *F* has been finished turned by a tool of radius ½ in., and that this tool has "dug-in" on the finishing cut—not an infrequent occurrence—it will leave score marks similar to those shown at 1, 2, 3, 4, etc. In the end elevation they will also be visible and have been shown in true projection, but each mark will terminate at its intersection with the flat sides of the base. If these terminal points be projected across to the front elevation, each will therefore be a point on the curve *E*, and joining them we shall obtain the shape of the curve on that view.

Before we consider more complicated sketches, it is advisable that we discuss typical errors which are made by the great majority of beginners in machine drawing, for if we see why they are wrong, and understand how they are rectified, this knowledge will help us considerably, not only in these isolated instances, but in several cases which are analogous.

In Fig. 18, attempts have been made to show sections taken through a counterbored hole (*a*) and a countersunk hole (*b*), but both are wrong.

If we consider a section through the table of a milling machine, the slots for the T-headed bolts will be as correctly shown in Fig. 18 (*c*), the space which accommodates the bolt shank and head extending the whole length of the table. It will be noticed that Fig. 18 (*a*) presents a similar figure, but is reversed, and this intends to show a counterbored hole drilled through a piece of metal, but not a slot passing from end to end.

The drilling and counterboring has caused definite edges, i.e. *A*, *B*, *C*, and *D*, and if we consult the half-plan we shall see that these edges do not pass longitudinally through the metal, but delineate the circumference of the circles so formed.

In the sectional front elevation these edges of the circumferences will be seen as a straight line, equal in length, of course, to the diameter of the hole, and a correct drawing would be as shown in Fig. 18 (*d*).

By similar reasoning it should be obvious that the corrected drawing of Fig. 18 (*b*) would be as shown at (*e*).

At *F*, three views of a hexagon nut are shown in correct projection. If in the elevation the nut is shown, as in this case, across its corners, it must in the end elevation be shown across flats, and in plan its corners must be on the horizontal ℄. There is no reason, of course, why it should not be shown across its flats in front elevation, but a mistake very common to beginners is to show it across its corners in all elevations, or if an end elevation is not given, the nut receives one-twelfth of a turn before appearing on the plan.

There must be agreement in all views, even in such small details, and this can only be obtained by observing the principles of projection.

The opportunity is taken of giving here the usual proportions adopted when drawing nuts and bolt heads. Both are standardized, and, for purposes of drawing, the proportions given are very close approximations.

When showing the nut across corners, if the curves at the top are shown do not show the corners rising to the full height of the nut. The curves are formed by removing them. In the end elevation, however, the flats will attain the full height if the chamfer is taken, as is usual, to the edge of the flats, i.e. the point *A* on the ℄ of the front elevation will appear at *A* in the end elevation.

The radius on the full width flat in front elevation is struck with a radius = *D* for both nut and bolt head, the smaller radii r_1 and r_2 can be found by trial. The construction line is shown to indicate that all radii should terminate at one level and touch the top face.

ASSEMBLY DRAWINGS

We have considered views pertaining to one detail only, but the majority of drawings concern several component parts which are assembled together to form one unit. The drawing which shows each component part in its respective position we will call the "assembly" drawing.

It is not customary, except on very simple units, to dimension the components in the assembly drawing, as the drawing would become too congested for satisfactory

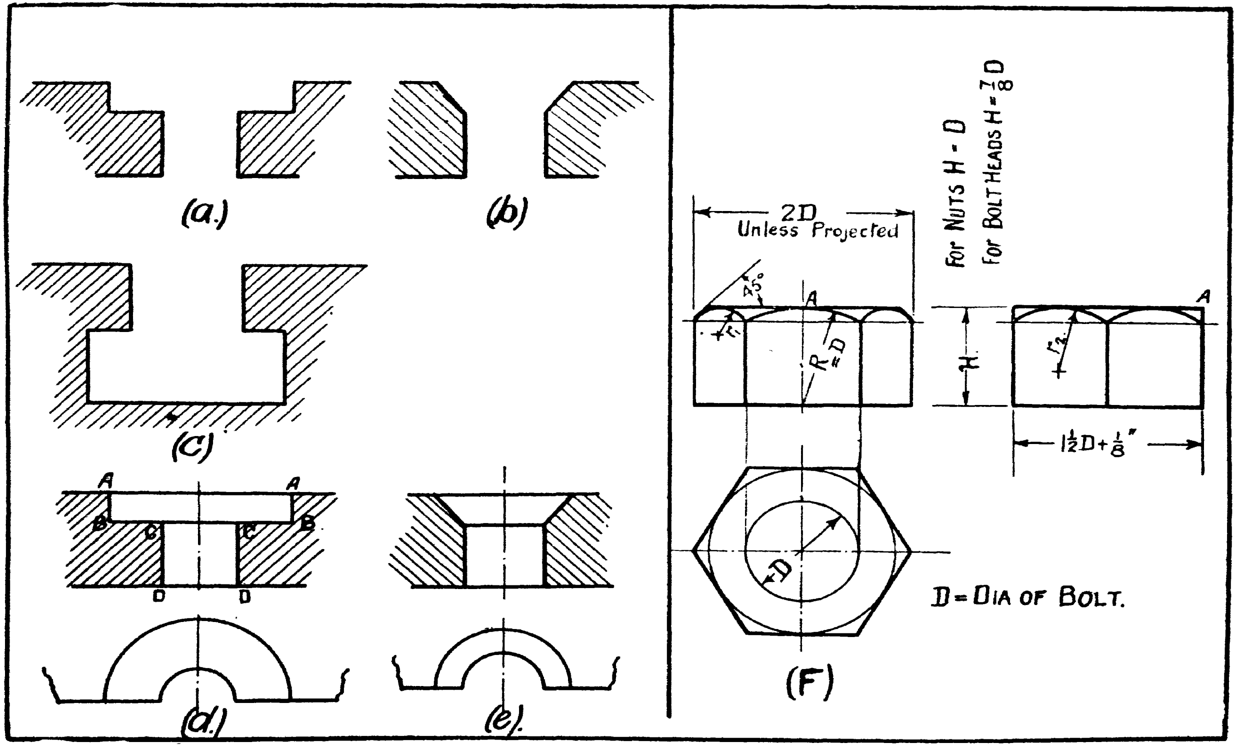


FIG. 18. WRONG AND CORRECT SECTIONAL VIEWS (LEFT), AND THE DRAWING OF A HEXAGONAL NUT (RIGHT)

dimensioning and reading. The various components are therefore picked out. and shown separately in detail, the resulting drawing being known as a " detail " drawing. Each detail is then given an identification symbol, either in the form of a number or letter, and by this symbol is identified on the assembly drawing.

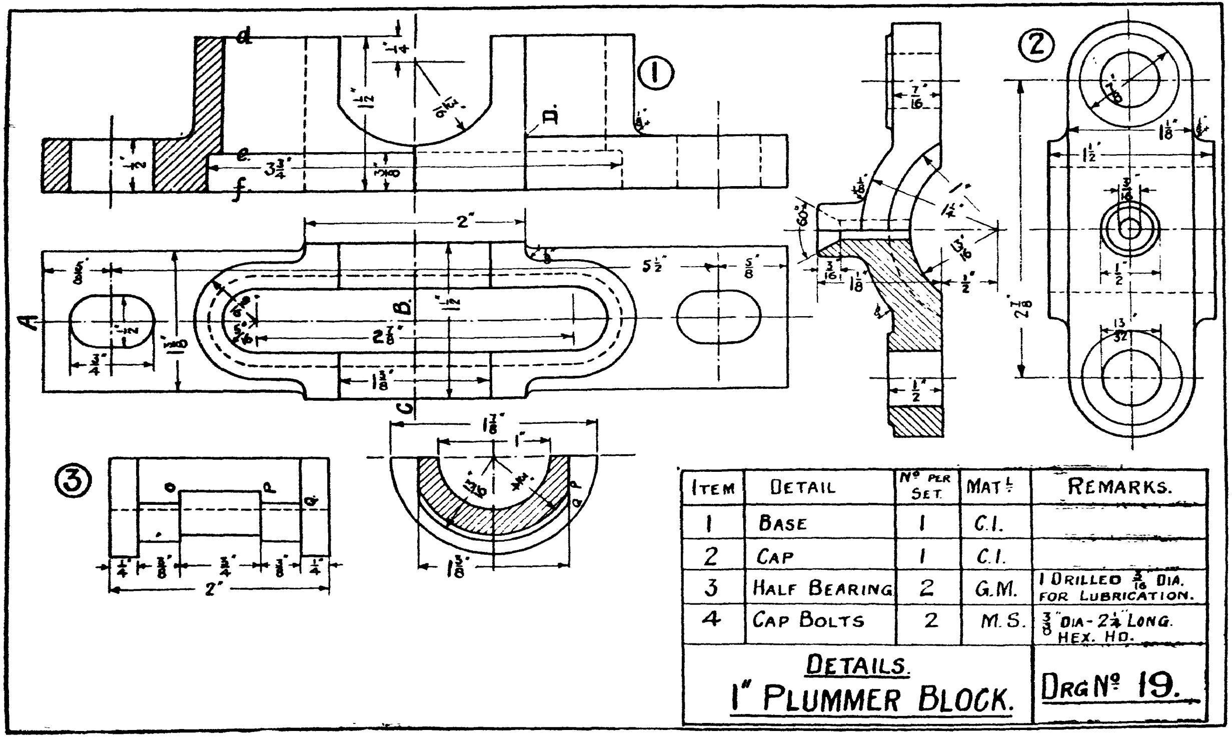
The manner in which detail drawings are prepared for issue to the shops depends to a large extent upon the nature, size, and number required of the complete product. Some prefer to show on one print as many details as can be conveniently arranged to scales which permit of easy reading (see Fig. 19).

At the bottom right-hand corner a schedule is given to include particulars, not only of all the details shown, but frequently of details which may be obtained from store, such as bolts, nuts, taper or split pins, washers, etc., for which a drawing is of course unnecessary.

When this system is used, and many sheets are necessary, it is good practice so to arrange the details that castings are shown together on one sheet, forgings on another, gearing on another, so that separate processes appear on separate sheets.

An alternative system favoured by many is to confine one detail to one sheet. The print is kept conveniently small (frequently foolscap size, 13 in. × 8 in. is sufficient) and is very suitable for use in the shops, with the added advantage that the print is issued only to the department concerned. It is desirable, however, when using this system that "limits" are given on all engaging dimensions, for in the absence of them, trouble is likely to arise in assembly since "mating" components are not readily distinguished during the process of manufacture.

Another drawing which is made is one termed the " general arrangement." It cannot be claimed that there is uniformity in the nomenclature of drawings.



ITEM	DETAIL	Nº PER SET	MATL.	REMARKS.
1	BASE	1	C.I.	
2	CAP	1	C.I.	
3	HALF BEARING	2	G.M.	1 DRILLED $\frac{3}{16}$ DIA. FOR LUBRICATION.
4	CAP BOLTS	2	M.S.	$\frac{3}{8}$" DIA - 2¼" LONG. HEX. HD.

DETAILS.
1" PLUMMER BLOCK.

DRG Nº 19.

FIG. 19. DETAIL DRAWING OF LIGHT TYPE PLUMMER BLOCK

It is the practice of some to apply "arrangement," and of others "general arrangement," to what has been called here an "assembly" drawing, but it is suggested that we apply

DETAIL to drawings which show particulars of individual components.

ASSEMBLY to drawings which show components grouped to form one completed unit.

GENERAL ARRANGEMENT to drawings which show completed units grouped to form one completed machine.

The details of a light type Plummer block are given in Fig. 19. The base casting is hollow, and recessed at its seating, to house the heads of the cap bolts, and to prevent their rotation when tightening. It is shown half in section and half in outside front elevation, and when this is done about a definite line, in this case the ℄, the line of demarcation between the two aspects is denoted by a firm full line, and the ℄ has been thickened-up accordingly.

To obtain such an elevation, we have cut along the ℄ from *A* towards *B* (see plan) and again along the other ℄ from *C* towards *B*, thereby removing the bottom left-hand quarter. In doing this we have had to cut through metal from *A* to the elongated slot, through which we have passed unhindered to its other edge, and there have cut through the full height of the body until we emerge into the central space to *B*. Then we have cut through from *C* towards *B*, hence the thickening-up of the ℄ in elevation, for an extent equal to the height of metal through which we have cut.

Now a front elevation will appear as shown, and the surfaces upon which the saw marks would appear, and to which allusion has been made, are indicated by the hatching—remembering that saw marks will not be visible on air.

When dealing with sections, it was stated that the position of a cutting plane was usually coincident with the ℄. If in this example we had selected our cutting plane in some position off the ℄, the elevation, if correctly projected, would not have been truly representative, as the lengths would not be true, the gaps would be shortened, and thicknesses exaggerated.

We must decide for ourselves when it is desirable to show a section, and also whether a part should be shown in outside elevation. When making a mechanical drawing, bear in mind that we must represent our ideas on paper in such a manner that they can be readily understood by any who have to read them. The value of a section is its ability to express an inner contour. Reverting to the drawing of the base, the inner detail is shown dotted in the outside elevation, as it is also in plan, but although all necessary information concerning the contour is there, it is less obvious than that shown in section. An outside elevation is also desirable, inasmuch as it shows the facing bossed up to receive the inside faces of the flanges on the brasses.

Analogous cases to the counterbored hole may be instanced at *d*, *e*, and *f*. It will be noticed that at *D* a line inclined at 45 degrees is shown. This indicates the intersection of equal radii at right angles.

No useful purpose would have been served if any part of the plan had been shown in section, and it is therefore shown as an outside view.

As an exercise in sketching, the beginner should make a sketch of an end elevation viewed from the left-hand end, and showing therefore a half section on the right-hand side of the ℄.

The outline of the brasses is perhaps rather less obvious than that of the cap. These are squared on the sides to the same width as the gap in the base, to prevent their rotation when in position. The seating is at each end, the central portion being reduced. A section has been taken on any plane through this reduced portion, i.e. between *O* and *P*, but, of course, at right angles to its axis. The points of intersection of the parallel sides and the two radii will be at *P* and *Q*, and by projecting these across to the end elevation we shall obtain their respective edges in that view.

It will be seen that the various details have been numbered and particulars given in the included schedule, which includes also the cap bolts. These will be required, but, being a stock accessory, need not be drawn as a detail.

In Fig. 20 an assembly drawing of the Plummer block is shown, together with an outline of construction. When starting on a drawing we must decide what views will be necessary, work out what the overall lengths of each will be, and then we can decide upon the scale to which we will make the drawing. Having decided this, draw in the ℄s. It will be noticed that these have been dimensioned on the construction drawing, but that has been done only as a guide. It will be found inadvisable to insert any dimensions until the drawing has reached a stage nearer to completion.

The general outline should not give trouble in actual drawing as it is merely a case of reproducing the details given, but in doing it do not actually measure any one dimension on both views. Draw it in one view, and project it on to the other by using the T- and set-squares; e.g. we already have the centres of the cap bolts indicated on the drawing, then taking $\frac{9}{16}$ in. in our compass, and using these centres, we can describe the semi-circles which determine the length and width of the body and cap in plan. Projecting this on to the elevation we shall obtain the lengths in elevation.

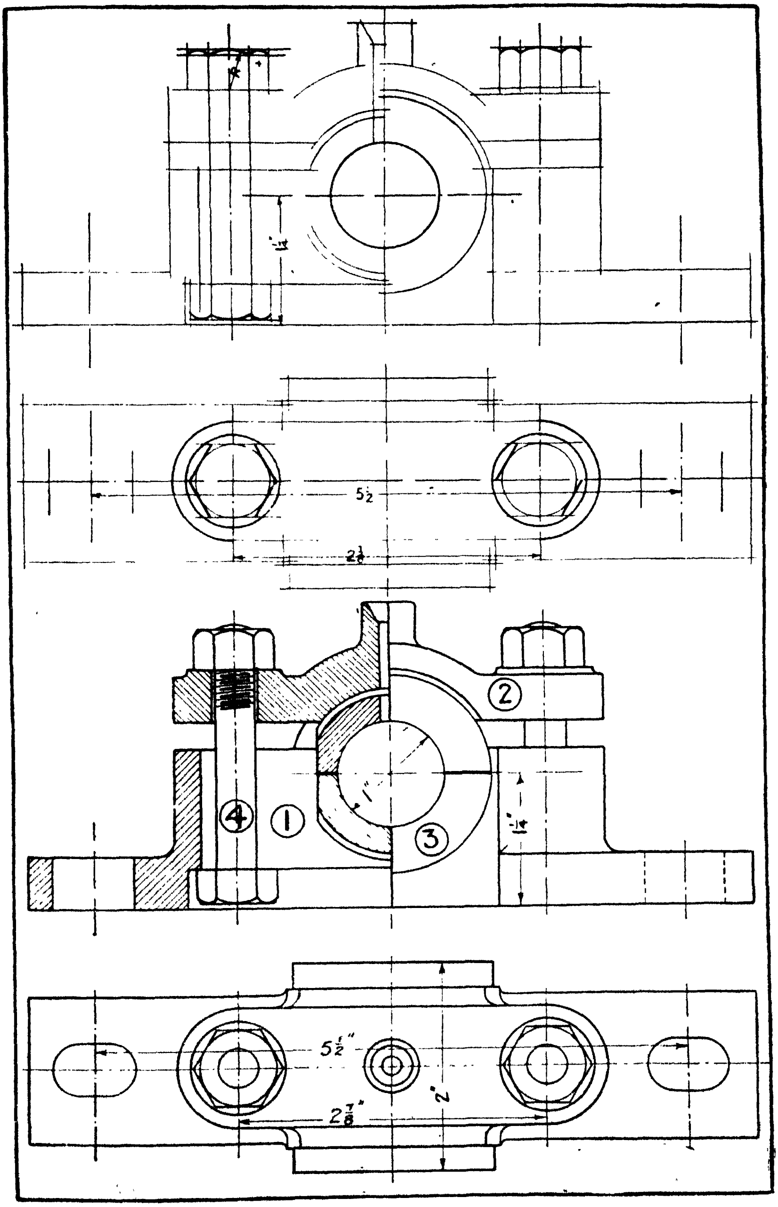


Fig. 20. Assembly Drawing of Plummer Block

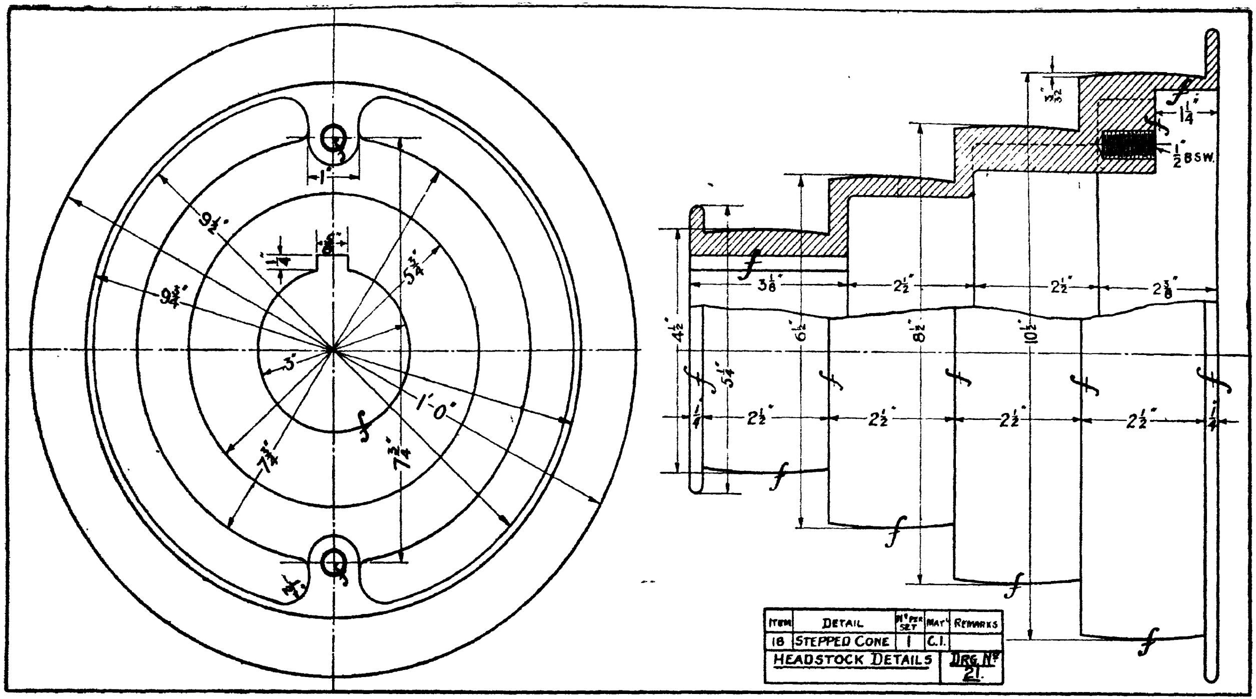


FIG. 21. DRAWING OF CIRCULAR STEPPED CASTING, SHOWING THE VARIOUS THICKNESSES OF THE METAL BY A BREAK IN THE ELEVATION DRAWING

It is not necessary to draw the whole of each view in construction outline, but only such portions of it as will enable us to pick up our final outline.

When a line and a radius meet, the join should not be seen, and to effect this it will be found easier to draw a line to connect radii than it is to draw a curve as a connector between two straight lines. When lining-in the drawing, therefore, line-in the small radii first, then the larger ones, and last of all the straight lines.

Referring to the completed assembly drawing, Fig. 20, there is a space between the cap and base through which the bolts pass, and will therefore be visible in section and outside elevation ; in the sectional view, we shall see the flange of the brass on the off-side. The section lining always slopes at 45 degrees, and that for any one continuous piece of metal is consistent in direction throughout the piece (see base and cap), but when two pieces butt, and are shown in section, the directions of slope are reversed to indicate that they are separate pieces.

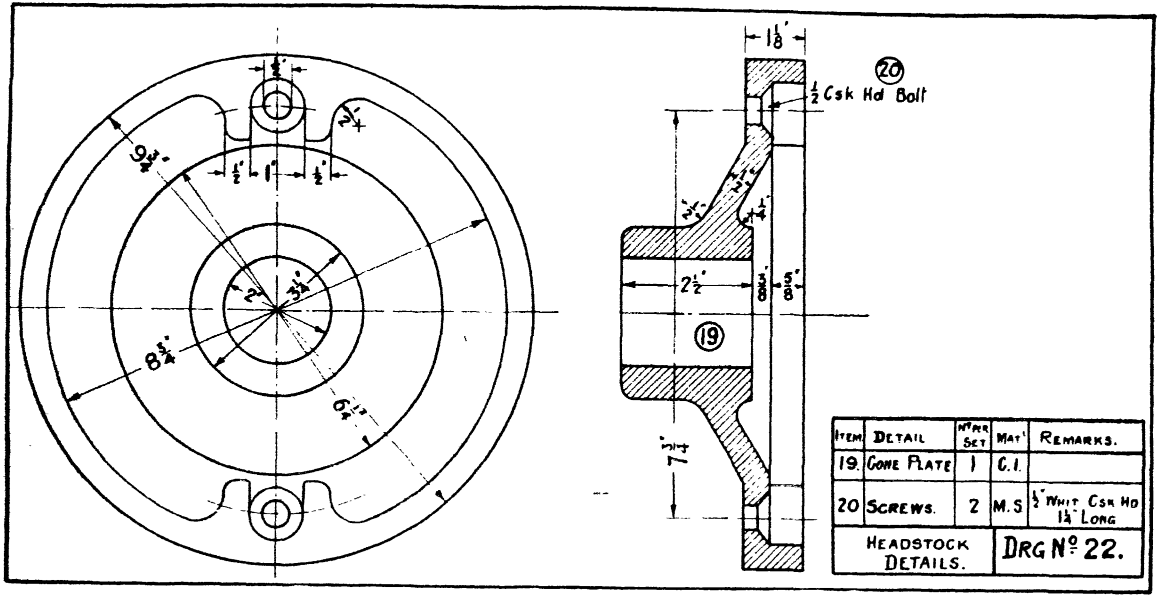
The beginner should now try to complete the sketch of the end elevation of the assembled Plummer block, the right-hand half still, of course, being in section.

It is perhaps advisable to point out here that the term "projected area" is one which is frequently applied to bearings, in what connection does not concern us at this stage, but the area to which this term has reference is, as its expression implies, the area which its projection would show, and that is its diameter × its length.

LATHE HEADSTOCK DETAILS

Fig. 21 gives an example of a break taken through a casting in order to give a section showing the various thicknesses.

The break in this case has not been taken on any



Item	Detail	Nº per Set	Mat¹	Remarks.
19.	Cone Plate	1	C.I.	
20	Screws.	2	M.S	½" Whit Csk Hd 1¼" Long

Headstock Details.

Drg Nº 22.

FIG. 22. DETAILS OF A CONE PLATE DESIGNED TO FIT THE STEPPED CONE SHOWN IN FIG. 21

definite line, and is then indicated by a firm and full, but irregular, line.

Two bosses are cast on the front end to receive the cone plate fixing screws, and the method of indicating the screw thread in each should be noted. The cones have been shown "crowned" to a radius of 10 in., but for machining purposes the dimension has been given as a drop of $\frac{3}{32}$ in. in half the width of each pulley.

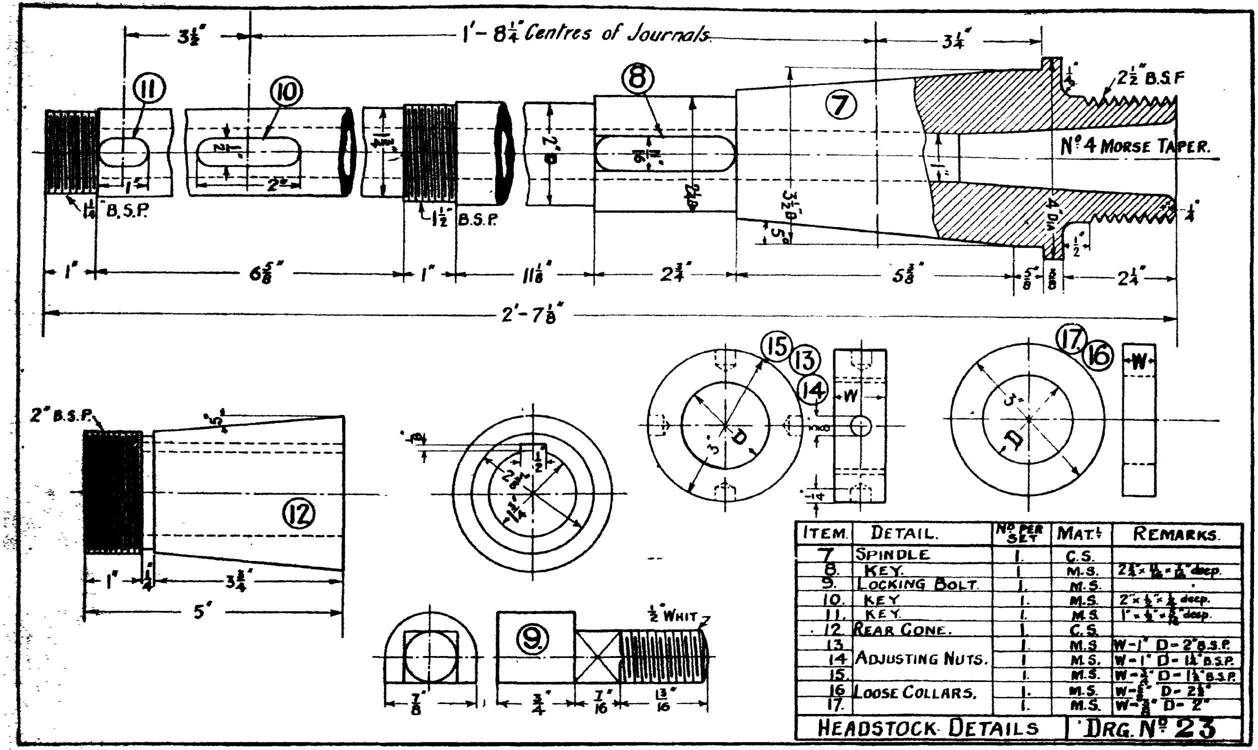
It will be seen in this drawing that certain surfaces are marked *f*, which indicates that they are to be *machined.* Other surfaces inside the casting are not working surfaces and are accordingly left rough-cast.

A part which is to be machined throughout from the solid bar, or which may be initially forged, or cast, and then machined on all surfaces, is not marked *f* on all its surfaces on the drawing, but the letters *f.a.o.* are conspicuously printed on the drawing to denote that the part is to be *machined all over.*

The cone plate which fits into the front end of the stepped cone is shown in Fig. 22. The countersunk (csk.) headed screws pass through the lugs, and so fix the plate on to the stepped cone. These lugs, of which there are two, extend to the face of the plate, and are open towards the centre to admit the head of the locking bolt when a direct drive is required. If using the back gear, the bolt must be dropped out of engagement altogether, the drive then being effected through the back gear to the spindle gear, which in turn drives the spindle, as it is keyed to it.

The front elevation of the plate has been shown entirely sectional, as this is more helpful than an outside elevation, whilst to show the lugs the end elevation must be viewed from the right-hand side, which has been done accordingly.

When drawing the details of a casting always avoid



ITEM.	DETAIL.	Nº PER SET	MAT.L	REMARKS.
7	SPINDLE	1.	C.S.	
8.	KEY.	1	M.S.	2¾″ × $\frac{11}{16}$ × $\frac{7}{16}$″ deep.
9.	LOCKING BOLT.	1.	M.S.	
10.	KEY	1.	M.S.	2″ × ½″ × ¼ deep.
11.	KEY.	1.	M.S.	1″ × ½″ × $\frac{5}{16}$″ deep.
12.	REAR CONE.	1.	C.S.	
13	ADJUSTING NUTS.	1.	M.S.	W-1″ D-2″ B.S.P.
14		1	M.S.	W-1″ D-1¼″ B.S.P.
15.		1.	M.S.	W-¾″ D-1½″ B.S.P.
16	LOOSE COLLARS.	1.	M.S.	W-⅝″ D-2¼″
17.		1.	M.S.	W-⅜″ D-2″

HEADSTOCK DETAILS DRG. Nº 23

FIG. 23. DETAIL DRAWING OF HEADSTOCK

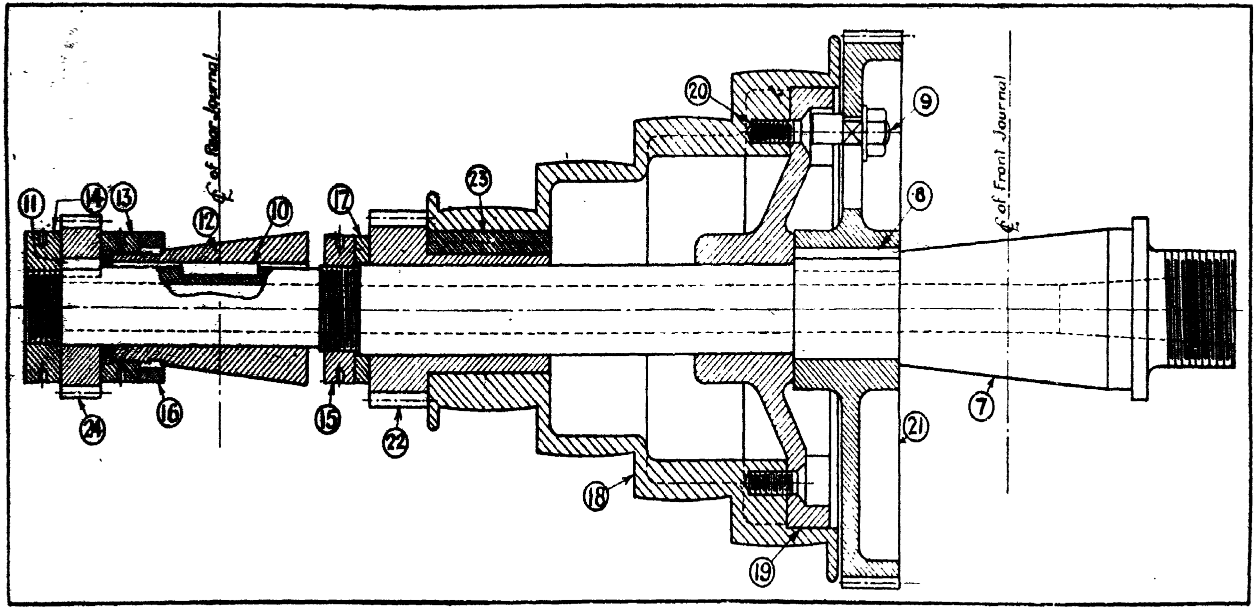


FIG. 24. A SECTIONAL ELEVATION DRAWING

showing sharp corners. In Figs. 21 and 22, square corners admittedly are shown in several instances, but they are on machined surfaces, and have resulted from the process of turning.

In Fig. 23 a break has again been made to show the spindle nose taper in section, and also three complete breaks to shorten the spindle length, two of the latter indicating that the section is round and hollow. It will be seen that a detail occurs between any two of the complete breaks, which explains the necessity of their frequent occurrence.

When dealing with screw threads, it was stated that the use of the B.S.P. thread was not limited to pipe work. The cone plate and spindle pinion run on the 2 in. diameter, and the rear cone on a diameter of $1\frac{3}{4}$ in., but between these two diameters we want to place an adjusting nut.

The $1\frac{1}{2}$ in. pipe thread has a crest diameter of 1·882 in., and therefore just below the 2 in. diameter, and core diameter of 1·766 in. which is just above the $1\frac{3}{4}$ in. diameter, and its small pitch will allow for fine adjustment to be made.

For similar reasons, B.S.P. threads have been adopted for the other adjusting nuts, and their proportions are equally accommodating.

Three sizes of adjusting nuts are required, but each has features which are common to the remaining two, the differences being in width and internal diameter. It is unnecessary in such cases to draw each separately, for by indicating these differences as *W* and *D* respectively, we can give the dimensions appropriate to each in the schedule against its own symbol.

A similar instance is that of the loose collars.

The locking bolt must be capable of sliding up or down the slot in the spindle gear, but must be prevented from rotation when tightening its nut. This is effected by providing a square under its head, and the diagonals seen in the front elevation indicate a squared surface. In Fig. 24, a sectional elevation is shown with the various details mounted on the spindle. It will be seen that the ℄ of each journal is indicated thereon, but as they do not have direct reference to details shown on the drawing they are indicated "℄ of - - - - - - -."

Now it may be questioned whether this is a section, seeing that various parts of it are shown in outside elevation. It is a matter of custom that when a shaft figures on the cutting place in a sectional view in this manner, it is left as an outside elevation unless there are specific reasons for showing it otherwise.

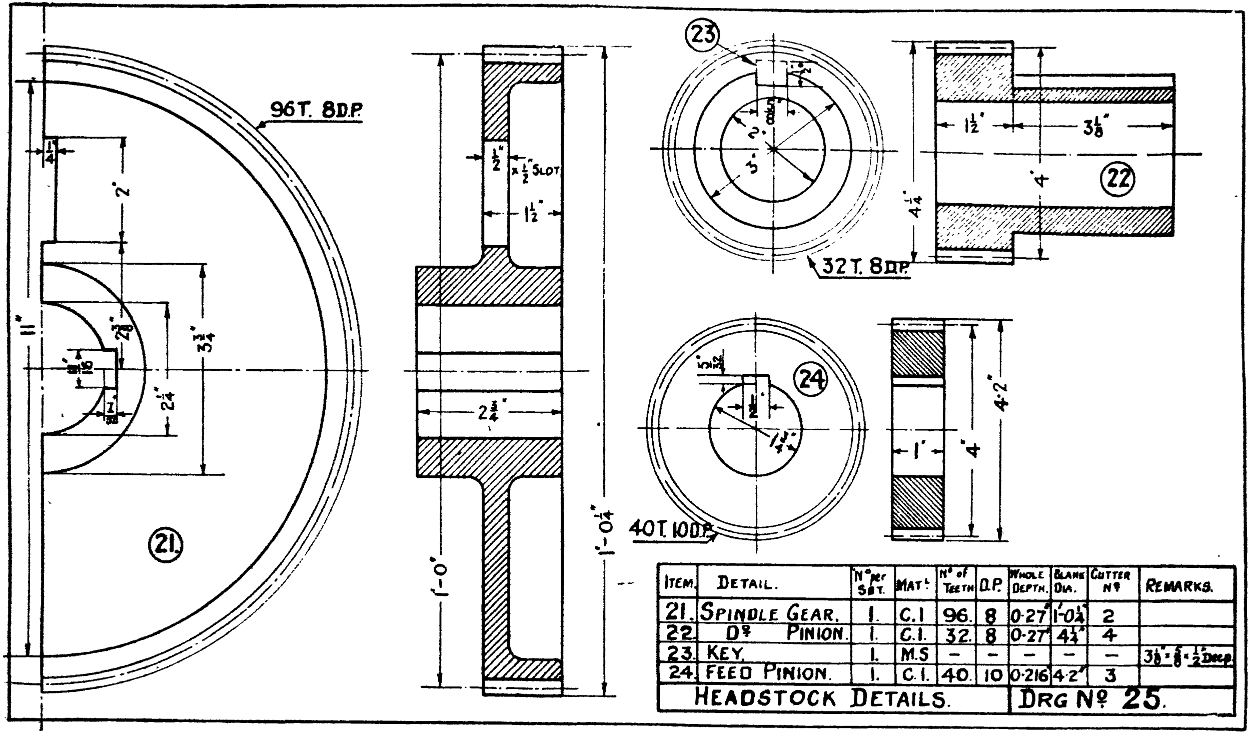
If a certain portion of it would be more clearly indicated when shown in section, we can make a break in the shaft, local to the part which we wish to emphasize. This has been instanced for the key in the rear cone.

For a similar reason nuts and bolts are not shown in section, but left as outside views, even though they may figure on the cutting plane.

The key between the spindle pinion and small end of stepped cone might also have been left in outside elevation, but it has been sectioned to illustrate the method of sectioning when more than two separate parts are adjacent. We are restricted to one angle of slope, and that limits us to two directions, but we can vary the spacing of the lines at will, and that method is adopted to meet such contingencies.

The drawing of the spindle gear is not identically the same as shown in its detail. It will be noticed that the keyway is shown vertically below the slot, but in the detail drawing (Fig. 25) it is at right angles to it.

In certain cases, the keyway through the boss would weaken it to such an extent that it is necessary to



ITEM.	DETAIL.	Nº per SET.	MATL.	Nº of TEETH	D.P.	WHOLE DEPTH.	BLANK DIA.	CUTTER Nº	REMARKS.
21.	SPINDLE GEAR.	1.	C.I	96.	8	0·27"	1'-0 1/4"	2	
22.	Dº PINION.	1.	C.I.	32.	8	0·27"	4 1/4"	4	
23.	KEY.	1.	M.S	–	–	–	–	–	3 1/8" × 5/8" × 1/2" Deep.
24.	FEED PINION.	1.	C.I.	40.	10	0·216	4·2"	3	

HEADSTOCK DETAILS. DRG Nº 25.

FIG. 25. DETAIL DRAWING OF SPINDLE GEAR

thicken-up the boss local to the keyway, but whether this thickening-up is necessary or not, the keyway should be kept off the ℄ of any slots which may occur in the web.

If it be a gear or pulley having arms instead of a web, put the keyway on the ℄ of one of the arms, and not between them.

We have yet to consider the details of the spindle gear and pinion, and in order to do so we must be acquainted with the proportions of gear wheel teeth. It is not within the scope of these pages to show how these proportions are derived, but it is within our province to derive the necessary dimensions from them. The vast majority of machine (m/c) cut gears have teeth of involute form, and the pitch adopted is that known as the "Diametral Pitch," abbreviated to *DP* or simply *P*. This, however, is somewhat of a misnomer, for it so happens that it does not refer to a pitch, but to a number—the number of teeth to every inch of the pitch circle diameter of the wheel. Of course, it has a corresponding circular pitch which, numerically, $= \frac{\pi}{DP}$. Referring to Fig. 25—

The spindle gear has 96 teeth of $8DP$, and this is given on a drawing as $96T\ 8DP$ or $96T\ 8P$, and from this we can determine the pitch circle diameter, which $= \frac{\text{Number of teeth } (N)}{DP} = \frac{96}{8} = 12 \text{ in.}$

Similarly, that of the pinion $= \frac{N}{DP} = \frac{32}{8} = 4 \text{ in.}$

The addendum $= \frac{1}{DP} = \frac{1}{8}''$ for both gear and pinion.

The dedendum $= \frac{1{\cdot}157}{DP} = 0{\cdot}144''$ for both gear and pinion.

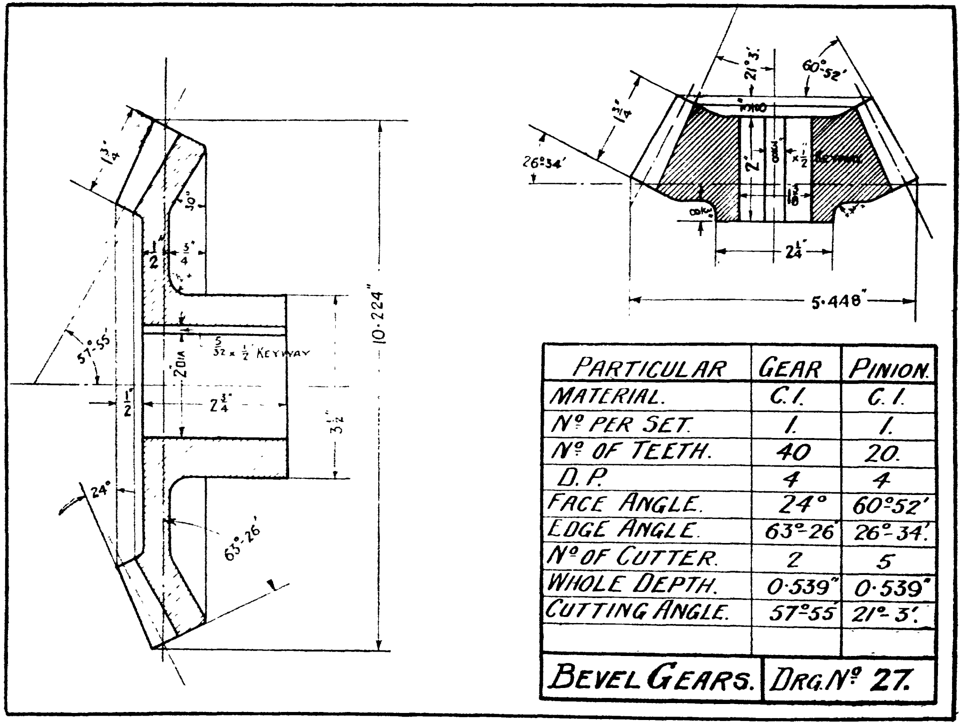
Therefore whole depth $= \frac{2{\cdot}157}{DP} = 0{\cdot}2696'' =$ say, 0·27 in. for gear and pinion.

Adding twice the addendum to the pitch circle diameter we shall obtain the outside diameter, or "blank" diameter, which for the gear and pinion becomes 12·25 and 4·25 in. respectively.

If the teeth are to be cut in the milling machine by a formed cutter, the information given in the schedule should include the number of the cutter to be used. This is not so necessary in the case of a spur gear as it is in the cases of helical and bevel gearing. In the case of the spur gear, the selection of the cutter is dependent entirely upon N; but in the helical gear is dependent not only upon N, but also upon the helix angle, and in the bevel upon N, and the pitch cone angle. It must be understood that this is applicable to teeth cut with a formed cutter. If they are generated by any one of the machines specially designed for that purpose, any reference to the number of cutter required will be irrelevant.

When certain outlines, however intricate they may be, are essential to information, they must be accurately drawn without consideration of the time involved, and although a mechanical drawing should always offer full information, yet there are instances when it is expedient to consider the relative values of time and usefulness. One instance is the representation of gear wheel teeth. To show these accurately will take considerable time, but if the information afforded by showing them is essential to the production of the gear, then we must show them. If not essential, then a conventional method will suffice.

When dealing with the correct method of dimensioning a drawing, it was stated that the dimensions should be those required by the man on the job, and if we



PARTICULAR	GEAR	PINION.
MATERIAL.	C.I.	C.I.
Nº PER SET.	1.	1.
Nº OF TEETH.	40	20.
D.P.	4	4
FACE ANGLE.	24°	60°52'
EDGE ANGLE.	63°-26'	26°-34'.
Nº OF CUTTER.	2	5
WHOLE DEPTH.	0·539"	0·539"
CUTTING ANGLE.	57°55'	21°-3'.

BEVEL GEARS. DRG. Nº 27.

FIG. 26. DETAIL DRAWING OF BEVEL GEAR AND ITS MATING PINION

consider the method he will adopt in cutting the gear we shall know then what information he requires.

He will index the blank (or divide it up into the requisite, say, 96 spaces) by using the dividing head, and feed a No. 2 8*DP* cutter, through the blank, for a whole depth of 0·27 in., and this will automatically form the tooth outline.

The drawing of a gear is therefore comparatively simple. The hub and its other details are shown in the orthodox manner, but the teeth may be indicated conventionally by construction circles to represent the addendum and dedendum of the teeth.

Wheels which are used to give a positive drive will gear correctly only when their pitch circles are just touching, and these are the basic lines of all our calculations. They will not be required by either the turner or the miller, but may be required by the erector if we have omitted to give the distance between the centres of the driving and driven gears—usually called the "centre distance."

If the pitch circles are just touching, the centre distance is obviously equal to the sum of their radii, or half the sum of the pitch circle diameters.

The centre distance of the headstock spindle and back gear shaft, when the back gear is in engagement, would therefore be 8 in.

BEVEL GEARS

Another form of drive with which we will have to deal is one in which the shafts are not parallel, as for spur gears, but at right angles. This is the most common form of bevel gear driving, though it must not be assumed that bevel gearing is limited to a right-angled drive. The shafts may be at any angle but in one plane if the teeth are to be radial.

A bevel gear having 40*T*, 4*DP* is shown in detail in

Fig. 26 together with its mating pinion of $20T$ of necessarily the same DP. This is known as a 2 : 1 gear ; if they each had the same number of teeth, they would be termed " mitre gears."

As for the spur gear, the actual drawing is not difficult. Both have been shown in section, and an end elevation has not been added, as it would not convey any additional information. Few dimensions are necessary, but these cannot be said to be easily obtained. The drawing of the hub and web is simple, but for the gear portion we must give the face, edge, and cutting angles, and also the blank diameter.

Now refer to Fig. 27, which shows the two wheels in gear, and the terms common to bevel gearing shown thereon.

To determine the required angles we must adopt one of two courses: either we must calculate them or we must draw them accurately to an appreciable scale, and measure the angles with a protractor ; the former method is to be preferred.

To draw the wheels in gear we must first determine their pitch diameters. The pitch diameter of the smaller end of the bevel will, of course, depend upon the width of face of the tooth, and reference to pitch diameter must therefore be applied to the large end.

This, as in the spur, $= \frac{N}{DP} = \frac{40}{4} = 10$ in. for the gear, and $\frac{20}{4} = 5$ in. for the pinion. Now set out our ℄s and $2\frac{1}{2}$ in. below O draw a horizontal line 10 in. long, i.e. 5 in. on either side of OA. This will then be the pitch diameter of the gear. At D erect a perpendicular, and mark off on this line $BE = 2\frac{1}{2}$ in. also. Then $DE =$ pitch diameter of pinion. Now join C, O, E (this will be a straight line) and OD. We have now

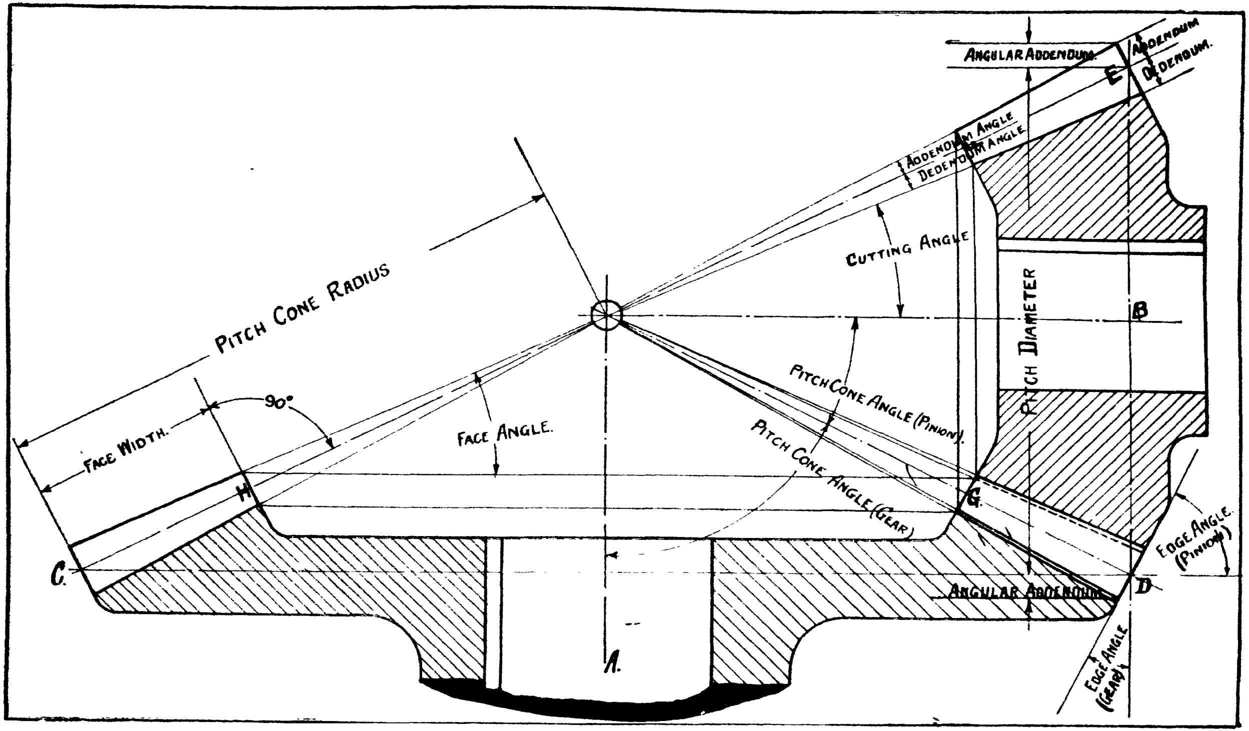


FIG. 27. SECTIONAL DRAWING OF TWO BEVEL GEARS IN MESH
With the terms used in connection with bevel gearing

formed the pitch cones which are to roll on one another. Now at E, D, and C mark off $1\frac{3}{4}$ in. (the width of tooth face) on these pitch cone radii to give F, G, and H respectively. At each of these points set off perpendiculars which will give the tooth edges. (Note. The tooth edges, both inner and outer, are now at right angles to the pitch cone radii.) At C, D (both sides), and E mark off on these tooth edges the addendum and dedendum, $\frac{1}{DP}$ and $\frac{1{\cdot}157}{DP}$ respectively, and join these points to the vertex O. The crests of the teeth and the roots of the spaces are radial. Now if we have drawn these accurately the various dimensions and angles may be measured.

To calculate them, the process is rather more tedious than difficult, for we cannot calculate them directly. If we study Fig. 27, we shall see that :—

The Face Angle = 90 degrees − (pitch cone angle + addendum angle).

Edge Angle, being at right angles to the pitch cone radius, = pitch cone angle, whose tangent $= \frac{N \text{ gear}}{N \text{ pinion}}$ or 2 for the gear, and $\frac{N \text{ pinion}}{N \text{ gear}}$ or $\frac{1}{2}$ for the pinion.

Cutting Angle = pitch cone angle − dedendum angle.

Outside Diameter = pitch diameter + twice the *angular* addendum.

It may with advantage be noted here that the *face angle* and *edge angle* are required when *turning* the blank and concern the turner only, but he is not interested in the *cutting angle.*

The tooth cutting is a subsequent operation on the finish turned blank, which will be elevated to the *cutting angle* for that purpose on the machine in which the teeth will be cut.

Now to obtain the required values it will be found necessary to make even further calculations which we will express in tabular form—

Required	Gear		Pinion	
	Proportion	Value	Proportion	Value
Pitch diameter	$\frac{N}{DP} = \frac{40}{4}$	(*a*) 10″	$\frac{N}{DP} = \frac{20}{4}$	(*b*) 5″
Addendum*	$\frac{1}{DP} = \frac{1}{4}$	(*c*) 0·25″	$\frac{1}{DP} = \frac{1}{4}$	(*d*) 0·25″
Dedendum*	$\frac{1{\cdot}157}{DP} = 0{\cdot}289$	(*e*) 0·289″	$\frac{1{\cdot}157}{DP} = 0{\cdot}289$	(*f*) 0·289″
Whole depth*	$\frac{2{\cdot}157}{DP}$	(*g*) 0·539″	$\frac{2{\cdot}157}{DP}$	(*h*) 0·539″
Pitch cone angle	$\tan = \frac{N(\text{gear})}{N(\text{pinion})}$	(*k*) 63° 26′	$\tan = \frac{N(\text{pinion})}{N(\text{gear})}$	(*l*) 26° 34′
Pitch cone radius*	$\frac{a}{2 \times \sin. k}$	(*m*) 5·59″	$\frac{b}{2 \sin l}$	(*n*) 5·59″
Addendum angle*	$\tan = \frac{c}{m}$	(*o*) 2° 34′	$\tan = \frac{d}{n}$	(*p*) 2° 34′
Dedendum angle*	$\tan = \frac{e}{m}$	(*q*) 2° 58′	$\tan = \frac{f}{n}$	(*r*) 2° 58′
Face angle	$90° - (k + o)$	(*s*) 24°	$90° - (l + p)$	(*t*) 60° 52′
Cutting angle	$k - q$	(*u*) 60° 28′	$l - r$	(*v*) 23° 36′
Angular addendum	$c \times \cos k$	(*w*) 0·112″	$d \times \cos l$	(*x*) 0·224″
Blank diameter	$a + 2w$	10·224″	$b + 2x$	5·448″

Values marked * are the same for both gear and pinion.

The letters (*a*), (*b*), (*c*), etc., have been used for condensing the proportions, e.g. it will be seen by referring to Fig. 27 that the sine of the pitch cone angle = pitch circle radius $\left(\text{or } \frac{\text{pitch diameter}}{2}\right)$ divided by pitch cone radius, or pitch cone radius

$$= \frac{\text{pitch diameter}}{2 \times \sin \text{pitch cone angle}}.$$

As we have found the pitch diameter at (*a*) and the pitch cone angle at (*k*), these symbols have been substituted, giving the proportion $= \frac{a}{2 \sin. k}$.

It will be noted also that the pitch cone angles, of the gear and pinion, and which equal the edge angle, are complementary.

When cutting the teeth, the dividing head spindle will be inclined to the machine table at an angle equal to the cutting angle which we have given on our drawing. That will make the root of the tooth space radial, but the sides of the teeth must also converge at an angle such that if they were produced, they too would meet at the cone vertex, i.e. they too are radial.

Now this cannot be accomplished in one cut, as that must inevitably leave a parallel-sided space, and the blank must therefore be set off the centre both ways, and slightly rotated, by means of the dividing head, so that subsequent cuts will equalize tooth and space on the pitch line at both large and small ends.

Now this will influence the size of cutter required, and to obtain this we must divide the number of teeth in the gear, and in the pinion, by the cosine of their respective pitch cone angles. This gives 89 for the gear and 22 for the pinion, which numbers represent the number of teeth for which the cutter should be selected, that required for the gear being No. 2, and for the pinion No. 5.

The cutting angles for the gear and pinion by actual measurement on Fig. 27 are 58° and 21° approximately, but by calculation are 60° 28′ and 23° 36′ respectively.

The dimensions which determine these angles are the pitch diameters, vertex distances, and dedendum. Small errors in these dimensions on the drawing will influence adversely the values of the angles.

in practice and giving their more important properties from the industrial and mechanical viewpoints.

COPPER

Copper, one of the most useful metals, has a specific gravity of 8·9 (annealed); this corresponds to a weight of 0·32 lb. per cub. in. Copper is very malleable; it can be beaten out into various shapes, if occasionally annealed to eliminate hammering hardness and stresses.

It is annealed at about 500° C. The process of annealing copper consists in heating it to this temperature and dropping it into cold water. This process removes stresses due to rolling or hammering, and leaves the metal in its softest state suitable for working.

Copper melts at 1083° C. (1981° F.), and when heated above this temperature burns with a green flame. When annealing, brazing, or soldering copper care should be taken not to " burn " the metal; this burning is not a difficult matter when using the open smith's hearth or forge fire.

Copper is an excellent conductor of heat. For this reason it is used for fire-tubes and fire-boxes of steam boilers, for steam and refrigerator pipes.

Copper has an electrical conductivity second only to silver and about 60 per cent better than aluminium, although the latter is a cheaper metal to employ. Copper is employed for the conducting cores of electrical cables, telephone and telegraph wires, bus-bars, and other conductors. The presence of small quantities of arsenic, cadmium, and silicon increases the strength and hardness of copper wire.

The mechanical strength properties of copper depend upon its purity and physical condition. Cold working by rolling, drawing, hammering, etc., increases the strength and hardness. The tensile strengths of pure copper in the cast, annealed, and cold-worked conditions are 10 to 11, 14 to 15, and 20 to 26 tons per sq. in., respectively. The hardnesses are 40 to 45, 45 to 55, and 80 to 100 on the Brinell hardness scale, respectively. As the tensile strength is increased by cold working the ductility is decreased, i.e. the metal becomes more brittle ; thus in frequent pressing, drawing, and spinning operations it must be annealed at intervals to prevent cracking. As copper is heated, progressively, its tensile strength is reduced but its ductility increases. Thus, at 500° C. the tensile strength falls to about 4 tons per sq. in. whilst the elongation is increased (at fracture) from 5 per cent at 0° to 15 per cent at 500° C.

Copper, although at one time considered difficult to weld, can now be welded satisfactorily by the oxy-acetylene flame and electric resistance butt-welding methods, if suitable precautions are taken. It can also be tinned, soft and hard soldered, and brazed with ease, using suitable solders and fluxes. Copper can now be cast satisfactorily if precautions are taken to avoid oxidizing of the molten metal.

BRASSES

Brasses are alloys of copper and zinc, often with the addition of small quantities of lead and tin ; sometimes iron also is present.

Ordinary brasses, as used for castings and general work, consist of about 65 to 70 per cent copper and 35 to 40 per cent zinc. They have a tensile or breaking strength of 12 to 20 tons per sq. in.

For *cheap castings* an inferior brass is generally used ; it contains more zinc, namely, from 40 to 50 per cent, and is less strong. Brasses containing from 80 per cent to 95 per cent of copper and the rest zinc are known as "gilding metals" on account of their golden colour. In the hard state their tensile strengths range from about 32 down to 26 tons per sq. in., respectively.

When annealed the corresponding values are 20 and 16 tons per sq. in., respectively.

An important group of brasses, suitable for cold-rolling into sheets and drawing into tubes and wire, contains from 65 to 75 per cent of copper. A typical alloy is "cartridge brass," with 70 per cent copper and 30 per cent zinc: it is capable of being pressed, stamped, or spun into complicated shapes and has the best combination of strength and ductility of all the brasses. Thus, the tensile strength is about 35 tons per sq. in. (hard) and 20 tons per sq. in. (annealed); the elongation or stretch at fracture in the latter case is no less than 65 per cent, so that the metal is very ductile and easy to work.

Another important group of brasses, known as "yellow metal," contains from 55 to 65 per cent copper and the rest zinc. Muntz metal, with 60 per cent copper, is a typical brass of this kind and it is particularly suitable for casting, hot stamping, and pressing. These brasses are, relatively, strong; thus Muntz metal in the hard condition has a tensile strength of 45 tons per sq. in. with 45 per cent elongation on a 2 in. length.

Special brasses, used commercially, contain additional elements, such as lead, nickel, manganese, or aluminium. Lead up to 3 per cent improves the machining properties and gives about 20 tons per sq. in. tensile strength; it is used for brass bars for turning purposes. Brasses with 60 per cent copper, 35 per cent zinc, and 5 per cent manganese (with small amounts of tin, iron, nickel, etc.) are known as "high tensile" brasses and give tensile strengths of 28 to 45 tons per sq. in.; such brasses are used for marine propellers. The corrosion resistance of brass to sea-water action is improved appreciably by the addition of about 2 per cent of aluminium to the 75 per cent copper and

23 per cent zinc brass: it has a tensile strength (hard) of 40 tons per sq. in.

NAVAL BRASS

This is a bright yellow metal containing about 60 to 62 per cent copper, 37 to 39 per cent zinc, and about 1 per cent tin. It resembles Muntz metal, to which group of brasses it belongs. The metal, in bar form, is used for certain turned parts requiring good strength and attractive appearance qualities.

BRONZES AND GUNMETAL

Copper, when alloyed with tin, forms a series of very useful alloys known as bronzes and gunmetal; the former are generally the stronger alloys. The ordinary gunmetal, so called because the early guns were made from it,* consists of 85 to 92 per cent of copper, and the rest tin. The more tin present the harder is the gunmetal. Thus the harder gunmetals contain about 12 to 15 per cent tin, and the softer ones from 7 to 10 per cent of tin.

Gunmetal is much used for bearings, and for parts subject to corrosive influences and requiring good strength properties. It can be cast into various shapes, and may be used where stronger castings than those in grey iron are required.

Gunmetal plain bearings are used in machines, engines, and instruments; although ball and roller bearings have to a great extent replaced gunmetal ones, where high speeds and heavy loads are the order.

A typical composition for a bearing type gunmetal consists of 88 to 92 per cent copper and the rest tin. The effect of too much copper in gunmetal is to make the metal porous and brittle. As the percentage of tin increases from 0 to 20 per cent, the tensile strength goes up from 12 to 14·7 tons per sq. in. (for 15 per cent tin) and then falls to 14·3 tons per sq. in.

---

* Gun fittings are still made from gunmetal.

Sometimes a small quantity of zinc is introduced into the composition. Thus the *Admiralty gunmetal* consists of copper, 88 per cent ; tin, 10 per cent ; and zinc 2 per cent ; this is a good bearing metal with a tensile strength of 14 tons per sq. in.

LEAD BRONZES

Lead bronzes are now used for the main and big-end bearings of high-duty Diesel and aircraft engines since they permit higher bearing loads. have a high resistance to wear and low frictional qualities ; these bronzes are superior to whitemetal for this purpose. A typical lead bronze contains 25 per cent to 30 per cent lead, 1 per cent tin, and the rest copper. The alloy has a high heat conductivity and therefore removes the frictional heat from bearings rapidly. Bearing loads as high as 1500 lb. per sq. in. can be used, whilst the coefficient of friction is only 0·002. It is usual to employ only a thin layer of lead bronze in a steel shell for Diesel and petrol engine bearings.

PHOSPHOR BRONZE

This is a very strong bronze consisting of the usual copper and tin, but with the addition of a very small quantity of phosphorus, namely, from 0·2 to 1·0 per cent. From 8 to 14 per cent of tin is generally used in this class of bronze. Phosphor bronze has a reddish-yellow appearance, and is noticeably darker than ordinary brass. It can be cast, rolled, and drawn into wire.

In the cast state phosphor bronze has a tensile strength of 14 to 18 tons per sq. in. If the moulds in which it is cast are of metal and are water-cooled the bronze is termed "chill" cast, and is appreciably harder, finer grained, and stronger ; the tensile strength in this case varies from 18 to 24 tons per sq. in ; it is also more ductile.

Rolling and drawing increase the strength of the metal ; thus phosphor bronze wire can be drawn to give a tensile strength of 120 to 150 tons per sq. in. (16 B.W.G. wire). If annealed, this wire is still stronger than mild steel, for it has a tensile strength of 40 to 75 tons per sq. in. Phosphor bronze strip is used for many engineering purposes, including flat springs for use in positions exposed to corrosive influences.

ALUMINIUM BRONZE

This is another of the stronger bronzes containing aluminium, in addition to tin and copper. There are several grades of this bronze, each grade depending upon the amount of aluminium present. Thus the " A " grade has 10 per cent, whilst the " E " grade has 1¼ per cent of aluminium. With the increase of the latter metal the tensile strength also increases from about 20 tons per sq. in. for no aluminium, up to 30 tons per sq. in. for 11 per cent aluminium ; the ductility increases also in a similar manner.

Aluminium bronze is malleable, i.e. it can be hammered, both in the hot and cold states ; it is used for parts requiring great strength and corrosion-resisting qualities, as in the case of pump parts, under-water fittings, and in certain chemical plants.

Aluminium bronze, when cast, shrinks more than ordinary brass, and solidifies rapidly, so that the feeders in the mould must be of ample size. Baked sand moulds are better than those of green sand except, perhaps, in the case of small castings.

Aluminium bronze can be rolled, drawn, swaged, forged hot, and spun. As with phosphor bronze, its mechanical properties are improved by rolling or drawing. It is best to forge or work aluminium bronze at a red heat. This bronze will solder and braze readily. Block tin solder with "killed" spirits is used in the former case, and a copper-zinc alloy, with borax as flux, in the latter.

MANGANESE BRONZE

Often known as white bronze, on account of its silvery appearance, manganese bronze is another well-known non-ferrous material much used in engineering work. The amount of manganese present varies from 0·10 to 20 per cent, depending upon the purpose for which it is required. The commercial grades contain from 1 to 5 per cent of manganese, and have a tensile strength of from 20 to 30 tons per sq. in. in the rolled condition, and 18 to 24 tons per sq. in. as cast; the latter metal is not very ductile, and apt to be somewhat brittle.

Manganese bronze is widely employed where a strong, non-corrodible metal is required. For example, it is used for bolts, nuts, pump rods, ship's plates, and marine propellers. It can be forged at a cherry-red heat and rolled either hot or cold.

Intricate shapes necessitating castings, and requiring the strength of mild steel but without the latter's tendency to rust, are frequently made in manganese bronze.

This bronze contains, in addition to copper and tin, from 2 to 5 per cent of silicon. The effect of the latter is to increase both the strength and the hardness, whilst giving the metal greatly increased resistance to corrosion; on the latter account silicon bronze is used for electrical purposes, notably for telegraph and telephone wires that are exposed to the corrosive influences of large manufacturing towns.

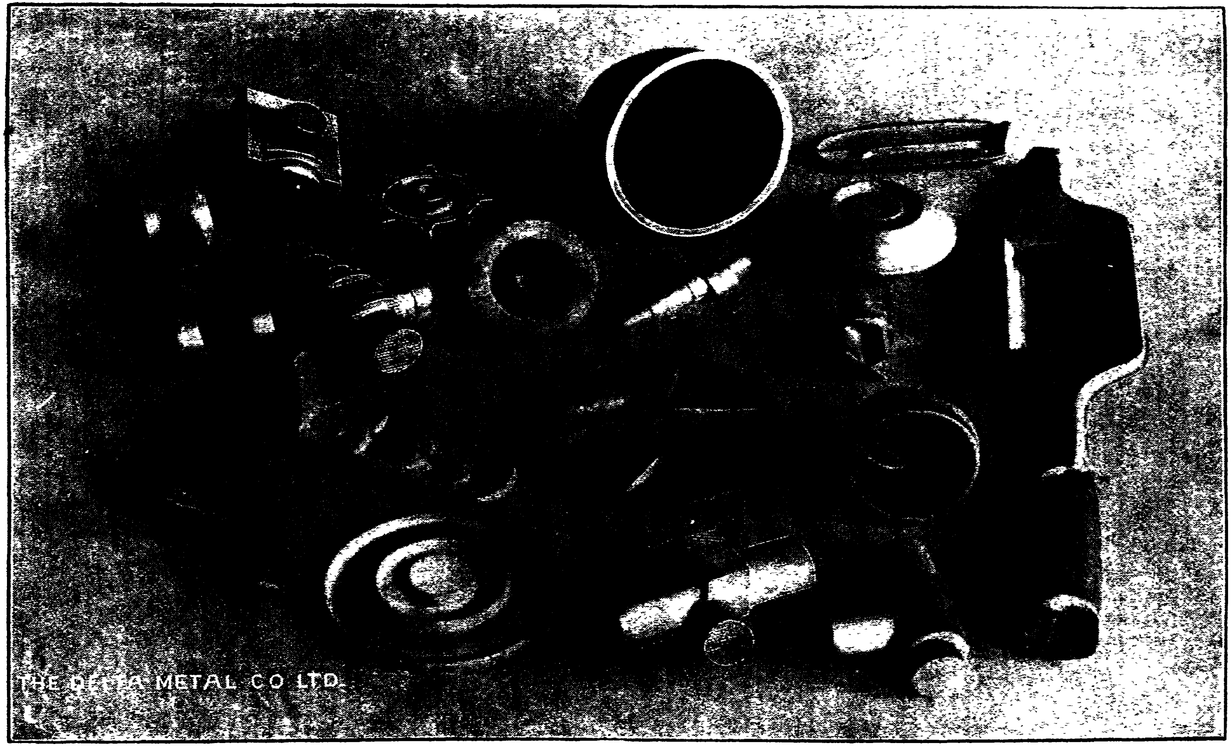


FIG. 1. BRONZE STAMPINGS AND FORGINGS [DELTA METAL]

TYPICAL BEARING BRONZES

Each of the different types of bearing bronze has its own special application in engineering, and as a general guide to the selection of the most suitable alloy the following table is given. The metals are given in the relative orders of their bearing strengths or loads.

TABLE I
SOME TYPICAL BEARING BRONZES

Nominal Percentage Composition by Weight				Average Mechanical Properties			Description and Applications
Copper	Tin	Lead	Zinc	Tensile Str'gth tons/ sq. in.	Elongation % on 2 in.	Brinell Hardness	
85	15			14	2	100	Hard-wearing bronze suitable for heavy compressive loads. Employed for locomotive slide valves, bearings for turntables, etc.
89	10 min.			18	4	100	PHOSPHOR-BRONZE, suitable for heavy loading, and very widely employed.
88	10		2	17	20	65	ADMIRALTY GUN-METAL. A bronze for general casting purposes, especially to resist marine corrosion. Suitable for bearings when lubrication is good.
80	10	10		15	15	65	LEAD BRONZES possess good anti-friction properties combined with plasticity. May be applied where lubrication is doubtful.
77	8	15		14	15	60	Suitable for use where lubrication or alignment is still less satisfactory than for the above.
85	5	5	5	13	16	55	An alloy suitable for general castings, such as hydraulic fittings not requiring high strength. Only occasionally used for bearings but suitable for bearing shells.
74	1·2 max.	25		8	15	30	This alloy has high thermal conductivity and is capable of carrying higher loads at high speeds than "white metals" and is therefore used for high-duty aeroplane and other engine crankshaft bearings, etc. Special technique in casting is required.

(*Copper Development Association.*)

ALUMINIUM AND ITS ALLOYS

Aluminium, like iron and copper, is a widely used metal in engineering work. During the last few years new alloys of aluminium have been discovered, with the result that these have to a large extent replaced steels in engineering parts requiring great strength for minimum weight. Particularly is this the case in motor-car and aeroplane constructional work.

It is interesting to note that if we represent the ratio of tensile strength to weight (of a cubic inch, say) of 30 ton mild steel by 100, then in the case of certain of the wrought aluminium alloys now in commercial use, the ratio is 360. This means that, *weight for weight*, these aluminium alloys are about 3½ times as strong as 30 ton mild steel; actually they are equivalent to 80 to 100 tons steel from this point of view. These facts will enable the reader to appreciate the principal reasons for the adoption of aluminium alloys in cases where the greatest strength is required, combined with minimum weight and increased resistance to atmospheric corrosion.

Aluminium alloys are now widely employed for domestic, industrial, and engineering purposes. Their principal domestic uses are in the form of stampings, pressings, and spinnings for cooking vessels, for which purpose their excellent heat conductivity, lightness, and resistance to food corrosion are particularly suited.

Industrially, these alloys are employed for tanks and steam-jacketed pans, steel-cored aluminium cables for high voltage distribution, for fast motor boat hulls, light machine and instrument castings and stampings, containers, and a variety of other purposes.

In automobiles, on account of their high strength-to-weight and resistance to corrosion, they are replacing steel to an appreciable extent. As an instance of the possible saving in weight it may be mentioned that the complete weight of a typical 16 h.p. saloon car is about 2850 lb. with steel body, petrol tank, and similar parts. If, however, aluminium alloys were used for the body, frame, front axle, crankcase and certain frame and engine components instead of steel a saving of about 2 cwt. could be effected.

Aluminium alloys are now being used for pistons, connecting rods, cylinders and cylinder heads, crankcases, valve covers, gear box and clutch casings, etc. Wheels, brake drums, and even complete combination chassis and body mountings have been made in these alloys. Fig. 2 shows the connecting rod and piston of the Lagonda engine, which are made of a light aluminium alloy, known as Hiduminium, whilst Fig. 3 illustrates a wide range of applications* of aluminium alloys to typical automobile details.

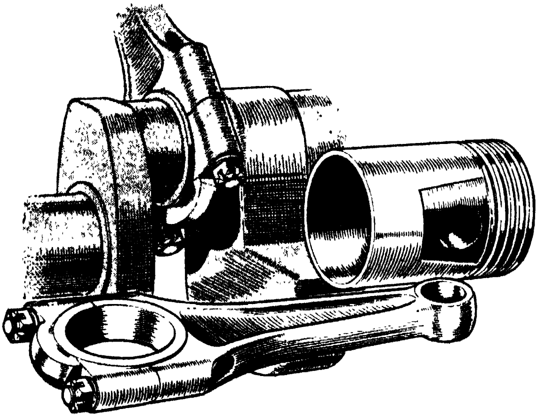


FIG. 2. ALUMINIUM ALLOY (HIDUMINIUM) PISTON AND CONNECTING ROD (LAGONDA)

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* *Aluminium in Motor Car Design,* British Aluminium Company Ltd., London

The airscrew blades of modern aircraft are now made largely as aluminium alloy forgings, whilst wing and fuselage frames are frequently built up of light aluminium alloy pressings riveted together.

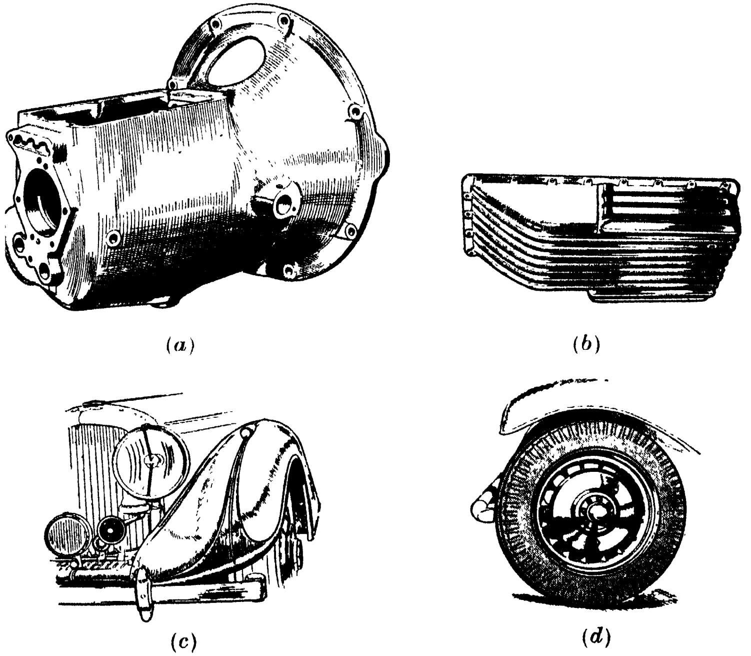

FIG. 3

(*a*) Gear Box and Clutch Housing Casting (Austin).
(*b*) Crankcase Sump Casting, showing Cooling Fins.
(*c*) Sheet Aluminium Alloy Wing.
(*d*) Aluminium Alloy Wheel with Integral Brake Drum (Bugatti).

SOME PROPERTIES OF ALUMINIUM

Perhaps the most interesting property of aluminium, from the engineer's point of view, is its extreme lightness. It has a specific gravity of 2·7, i.e. it weighs 2·7 times as much as an equal volume of distilled water. Steel, on the other hand weighs 7·8 times as much, so that, roughly speaking, aluminium is about one-third the weight of steel. A cubic inch of aluminium weighs ·95 lb. Aluminium is an excellent conductor of heat and also of electricity; it is greatly superior to steel in these respects. Aluminium has a heat expansion coefficient about 2½ times as great as that of steel or cast iron. In consequence when aluminium pistons are used in steel or cast-iron cylinders it is necessary to allow greater clearances than for steel pistons. In order, however, to prevent knocking or "piston slap" when the engine is started from the cold it is usual either to employ a split skirt—giving a spring effect—or to use a combination steel and aluminium alloy piston; other special designs of piston are used to prevent this knocking action.

As a conductor of electricity, aluminium is next in the scale to copper. Silver, the best conductor, being represented by 100, copper is 97·5, and aluminium 59·5. Aluminium is both cheaper and much lighter than copper, and is replacing the latter metal for many electrical purposes.

The tensile strength of rolled aluminium is about 6 tons per sq. in. in the annealed state, and 9 tons (minimum) in the hard drawn or rolled state. Sandcast aluminium has a tensile strength of 5·5 to 6·0 tons per sq. in. The aluminium alloys are very much stronger than the pure metal. Aluminium is not affected by ordinary atmospheric influences, but is corroded by sea-water. It is attacked by caustic alkalis, such as caustic soda, and by hydrochloric acid. Ordinary washing soda (carbonate of soda) slowly attacks aluminium; for this reason aluminium cooking vessels and domestic ware should not be washed in water containing soda.

Aluminium can be spun, hammered, beaten, and generally worked very readily, but frequent annealing is necessary.

ALUMINIUM JOINING METHODS

Aluminium and its light alloys can be joined readily by the oxy-acetylene and electric welding methods. For gas welding the welding rod should be of pure aluminium and a special flux in powder form employed to attack the oxide formed. Full particulars of the recommended welding methods for this metal are given in a publication of the British Aluminium Company Ltd., on "Aluminium Jointing."

Aluminium can now be soldered satisfactorily by three different methods known, respectively, as hard, soft, and reaction soldering. In the hard soldering method an aluminium alloy solder melting between 500° and 600° C. is used; the solder contains about 12 per cent silicon. The oxide formed is removed by an alkaline halide flux. The joints thus formed with the aid of the gas blowpipe are strong and permanent. Soft soldering is more difficult and generally less reliable since the joints will not withstand the action of boiling water or steam without protection. The method consists in cleaning the surface to be soldered and heating it until the solder melts on it. The molten solder is made to adhere by scraping through it with a scraper or wire brush so as to break up the oxide film; once the latter is broken it cannot reform under the solder and the latter will then adhere to the metal. In reaction soldering a chemical mixture is used as the solder and is spread on the parts to be jointed and heated by a blowpipe to about 200° C. The resulting chemical reaction leaves a deposit of pure zinc in the molten condition on the surfaces to be joined. The zinc flows readily between the surfaces and edges and forms an excellent joint.

A satisfactory solder for aluminium used in a similar method to soft soldering is that known as "Alunize."

It has been used for building up aluminium alloy tubing joints for cycle frames, but is of general application to various soldering operations.

ANNEALING ALUMINIUM

Aluminium melts at 659° C., and is annealed by heating to 350° C., exposing the metal for a few minutes only to this temperature and afterwards quenching either in air or water. In panel-beating work, where the objects are of awkward shapes, the usual method is to employ a portable gas blowpipe, which is played over the work until the required temperature is obtained. A rough workshop method of testing the temperature is to rub the surface with a dry match-stick from time to time, the heating being stopped when the metal is hot enough to char the wood. In the case of press and similar work the articles are annealed in a large muffle furnace.

In the case of aluminium alloys the temperature employed has an important bearing upon the results obtained, and the instructions of the alloy manufacturers should therefore always be followed.

MACHINING ALUMINIUM AND ITS ALLOYS

Tools used for turning aluminium should always be ground and finished with the keenest edges ; it is best to use an oilstone to remove the grindstone marks when finishing. The top surface of the tool should be left as smooth as possible so as to offer the minimum resistance to the turnings.

The clearance angle between the tool and the work should be 20 degrees, with a top rake of about 40 degrees for the softer alloys, rising to 30 degrees for the harder alloys. For rough cutting work on rigid parts as much as $\frac{1}{4}$ in. can be taken off in a single cut, when running at a cutting speed of 300 to 400 ft. per min.; it is advisable to use a lubricant, such as paraffin, or paraffin and lard oil in equal parts, when taking these heavy cuts.

For finishing purposes a machining speed of 600 to 800 ft. per min. can be used when using carbon steel tools; with alloy high-speed tool steels a higher finishing speed is permissible.

When *drilling* aluminium ordinary twist drills can be used, although the use of flat drills is often applicable. The cutting edges of the drills should be kept very keen. Aluminium should be drilled at a high speed, but with a light pressure for the feed. The best peripheral speed is from 150 to 200 ft. per min.; this means that a 1 in. drill should be run at 600 rev. per min., a ½ in. drill at 1200 rev. per min., and a ¼ in. drill at 2400 rev. per min.

In *milling* operations the teeth of the cutter are set a little farther apart in order to reduce the clogging tendency of the cuttings. A copious supply of soapy water should be used to wash away the latter, whilst paraffin should be used for final polish finishing in milling operations. When *grinding* aluminium the special abrasive stones made for this metal and its alloys should be used; usually the harder the work the softer the abrasive stone. High speeds up to 10,000 ft. per min. should be used for carborundum wheels, and about 6000 ft. per min. for wheels with shellac or other soft binders.

For *sawing* aluminium a band saw of the wood-working type should be used. The teeth should be large and the cutting speed about 600 ft. per min.

SPINNING ALUMINIUM

Spinning in aluminium, where a large number of articles is not required, is generally a much cheaper operation than press work. Blanks as large as 6 ft. in diameter can be spun into a variety of shapes economically. The process consists in forcing, by means of hand tools, a sheet metal blank over a wood or metal former. The metal blank is held tightly against the rotating former or "chuck" by means of a wooden centre piece carried by the tailstock of the lathe, and the necessary pressure is applied by a lever motion of the tool acting against a pin on the lathe rest. The linear speed at the edge of the aluminium disc should be about 3000 ft. per min.

Hard wood such as beech, boxwood, or lignum-vitae is used for the chucks. Before and during the spinning process the blanks should be lubricated with vaseline or lard oil applied with a rag or brush.

FINISHING ALUMINIUM SURFACES

Aluminium and most of its alloys can best be *polished* after machining in the usual manner for brass, so as to leave a good surface, with a polishing buff, using a greasy tripoli compound. Aluminium castings can be finished by tumbling in a barrel with steel balls and scrap metal.

For obtaining a *frosted finish* the articles should be cleaned and then dipped in a hot solution of caustic soda containing 2 lb. of soda to the gallon. They are then washed, and dipped in a 15 per cent solution of nitric acid ; they are then washed in water and dried in hot sawdust. *Scratch-brushing* is another method of obtaining a fine-grained finish to aluminium. In this case a fine steel wire brush is run at about 1500 rev. per min. and the aluminium held lightly against it.

Sand blasting is a quick, inexpensive method of giving a matt surface to aluminium. A fine sand impinging at a low pressure gives a fine grained finish suitable for instruments and dials, whilst a coarse sand used under high pressure gives a coarse crystalline finish.

ALUMINIUM ALLOYS

The alloys of aluminium, with relatively small proportions of other metals such as copper, magnesium, nickel, zinc, silicon, and iron, yield, in most cases, stronger metals than aluminium itself. In the case of certain of these alloys the strength of steel is obtained with the lightness of aluminium itself. The commercial alloys of aluminium are known under special names, of which Duralumin, Lautal, Alpax, Aeromin, Magnalium, Duralium are typical examples. Other alloys of particular interest and utility, evolved by the National Physical Laboratory, include those known as L.8, "Y" alloy, and others known in the series of zinc-aluminium, silicon-aluminium, and copper-aluminium. The most important of the aluminium alloys belong to this class.

We shall refer to a few of the most useful commercial and other alloys now in use.

DURALUMIN

This is an aluminium alloy containing copper, manganese, and magnesium. The specific gravity is 2·75 to 2·84, being about 2·8 on the average ; a cubic inch weighs 1·623 oz. (for steel this figure is 4·55 oz.). Although only one-third the weight of mild steel, duralumin has the same hardness and strength, so that its use effects a big saving in weight ; for this reason it is much used on aeroplanes for wing structures, metal fittings, and pulleys, on airships for the framework and engine car construction, and in petrol engines for connecting rods ; it has also been used for chassis frames.

AGE HARDENING OF DURALUMIN

In common with certain other aluminium alloys, duralumin possesses the unusual property of progressive hardening after heat treatment. Thus, if the alloy is heated to about 500° C. and quenched in water it afterwards hardens and increases in strength gradually over a period of several days. Thus, in the case of a specimen tested immediately after quenching the tensile strength was 16·5 tons per sq. in.; 10 hours later it had risen in a similar specimen to 21·5 tons per sq. in., whilst 3 days later it was 26·5 tons per sq. in. This increase in strength is also accompanied by an increase in hardness, and these increments continue over a period of weeks but at a greatly reduced rate.

Duralumin sheets used for bending and other forming operations should be worked soon after quenching; otherwise, if left for a day or two, they become too brittle.

The strongest duralumin is the cold-worked and "aged" sheet variety which in thin plates of about $\frac{1}{10}$ in. thick gives a tensile strength of about 40 tons per sq. in., but with only about 3 per cent stretch. Thicker plates of $\frac{1}{4}$ in. thickness give about 30 tons per sq. in. tensile strength.

Duralumin resists air and sea-water corrosion, but it is advisable to protect it by surface treatment such as anodizing or lacquering. The alloy is available in the form of rolled bar, sheet, hot stampings and forgings, but cannot be cast satisfactorily. It should not be used in exposed positions in contact with other metals such as steel or brass as corrosion occurs at the junctions of these metals. Duralumin rivets are much used in aircraft production work, but must be used in the softer condition, before age-hardening sets in. It is now the custom to store annealed rivets in refrigerators as the low temperature retards the age-hardening process for an appreciable period of time.

ALUMINIUM-COPPER ALLOYS

The addition of copper to aluminium hardens it, and produces a hard alloy that casts well and is strong at high temperatures. These alloys are much used for motor and aircraft engine pistons. The 3L.11 alloy contains from 6 to 8 per cent copper, and the 2L.8 alloy from 11 to 13 per cent. Both alloys are now made to British Engineering Standards Association specifications; they give tensile strengths of about 9 tons per sq. in. as cast.

"Y" ALLOY

This important alloy, developed at the National Physical Laboratory, contains 1·5 per cent magnesium, 2 per cent nickel, 4 per cent copper, and the rest aluminium.

It can be cast and also wrought like duralumin. As in the case of the latter alloy, it requires heat treatment subsequent to working, in order to develop its full strength; it undergoes a similar age-hardening process, and attains a final tensile strength in the cast and heat-treated condition up to 22 tons per sq. in.; in the cast state it is about 13 tons per sq. in.

HIDUMINIUM ALLOYS

An important group of aluminium alloys developed originally at the Rolls Royce Laboratories and now produced by High Duty Alloys, Ltd., Slough, is that known as the "Hiduminium" R.R. Alloys. These alloys are available in various grades for casting (sand and die), forging, extrusion, sheet, rod and other drawn sections.

A typical casting alloy for aircraft cylinders, pistons, brake shoes, levers, etc., is the R.R.53, which has a specific gravity of 2·73 and melting point of 635° C.

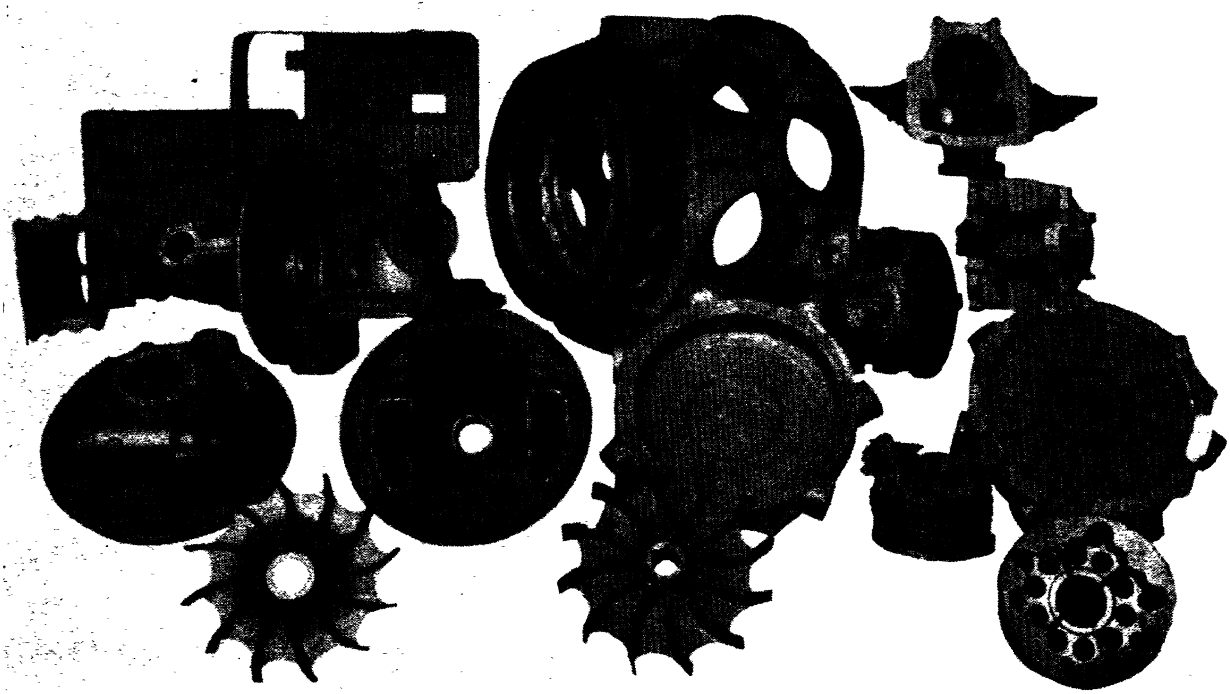

FIG. 4. TYPICAL EXAMPLES OF AIRCRAFT ENGINE ALUMINIUM ALLOY (HIDUMINIUM) CASTINGS

It is heat-treated by heating to 530° C. for not less than 2 hours and quenching in water at 70° to 100° C.; this alloy is an age-hardening one, and as heat-treated gives a tensile strength of 18 to 23 tons per sq. in.

A typical wrought alloy used for stampings and forgings, such as connecting rods, bearing caps, rolled bars and sections, airscrew blades, etc., is R.R.56. As quenched from 520° C. it gives a tensile strength of about 22 tons per sq. in., but in the age-hardened condition this is increased to 24 to 29 tons per sq. in.

(*British Aluminium Co. Ltd.*)

FIG. 5. HIGH STRENGTH LIGHT ALUMINIUM ALLOY PISTONS FOR DIESEL AND PETROL ENGINES

Excellent die cast parts, such as crankcase units, cylinder heads, pistons, levers, etc., can be made from R.R.50 alloy, with tensile strengths in the heat-treated condition of 13 to 16 tons per sq. in.

SOME OTHER ALUMINIUM ALLOYS

Aluminium alloys containing copper and zinc are widely used for casting purposes. A typical alloy is the B.S. Specification one known as 3L.5. Silicon is a useful addition for hardening and strengthening aluminium; typical alloys are the BA/37, Alpax, Silumin, Wilmil, and Lautal. Another group of alloys contains magnesium and manganese; the alloy known as "Birmabright," used for all-metal motor boats, belongs to this class. Magnalium is an aluminium alloy containing from 2 to 10 per cent of magnesium and a small percentage of nickel: it is actually lighter than aluminium and gives tensile strengths in the cast and rolled conditions of 9 and 23 tons per sq. in., respectively.

"L.28" ALLOY

This is a standard (British Engineering Standards Association) copper-zinc alloy of aluminium, containing about 3 per cent copper and 20 per cent zinc. It gives a tensile strength of 25 tons per sq. in. in the rolled sheet condition.

ANODIC OXIDATION OF ALUMINIUM ALLOYS

This much-used method of protecting the surfaces of aluminium alloys against corrosion is based on the principle of forming a thin surface layer of aluminium oxide or hydroxide which protects the metal underneath. The surface layer is produced by making the metal an anode in an electrolytic bath of dilute chromic acid, using a carbon cathode. This gives a hard and grey form of aluminium oxide which is firmly adherent and will not crack when the sheet metal is bent. Pistons of automobile engines are frequently treated in this manner to give greater surface hardness and longer life. The electrolyte consists of 3 per cent chromic acid solution and is worked at 40° C. with a current density of 3 to 4 amperes per sq. ft. of surface and a voltage of up to 50.

ALCLAD

This is the name given to aluminium alloy sheets which have been treated so as to have surface layers of pure aluminium, since the latter is an excellent protection against corrosion. Corrosion tests made on Alclad show that if the exposed edges of the metal are suitably protected the alloy offers a great resistance to attack by atmospheric and salt water spray or sea air over long periods.

MAGNESIUM ALLOYS

Magnesium is a light metal having a specific gravity of only 1·7 as compared with about 2·7 for pure aluminium. It forms, with small percentages of other metals, such as copper, aluminium, zinc, and silicon, a series of important light alloys of engineering application, having specific gravities of 1·8 to 1·9, but with tensile strengths in the cast condition up to 16 tons per sq. in. and in the hard rolled or forged condition up to about 24 tons per sq. in.

If we consider two alloys, one of aluminium and the other of magnesium, with the same tensile strengths, e.g. 20 tons per sq. in., the latter alloy will have only about 66 per cent of the weight of the former, so that a considerable saving in weight is possible by substituting the magnesium for the aluminium alloy. In aircraft engineering, full use is being made of this important property, so that parts such as petrol tanks, crankcases of engines, carburettor bodies, airframe components (control wheels, levers, landing wheels, etc.), airscrew blades, etc., are now frequently of this alloy.

A typical magnesium group of alloys, having a specific gravity of 1·81 to 1·83, is the Elektron one, which includes suitable forms for sand and die castings, rods, bars, tubes, sheets, extruded sections, angles, channels, forgings, pressings and stampings. These alloys are widely used for automobile, aircraft and other light engineering parts. The melting point of the casting grade is about 635° C. and castings show about 1·3 per cent shrinkage; the tensile strength is 13 to 15 tons per sq. in.

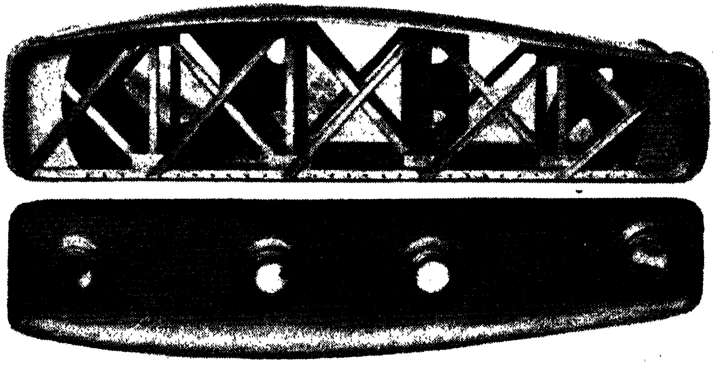

Fig. 6. An Aircraft Petrol Tank Made of Elektron Alloy

Elektron alloys are easily machined at fairly high cutting speeds up to about 1000 ft. per min., using sharp tools, preferably of high-speed steel, those tipped with tungsten carbide, e.g. Ardoloy and Wimet, and also Stellited tools.

Elektron can be welded satisfactorily, if suitable precautions are taken, by the oxy-acetylene process, using special welding rods and fluxes which are provided by The British Oxygen Company Ltd., London.

When machining Elektron and similar magnesium alloys a certain amount of care is necessary to avoid sparks due to blunt tools or sand or slag inclusions which might ignite the fine turnings or powder produced and thus cause the characteristic ignition associated with magnesium. Fire or water extinguishers should not be used in such cases; a copious supply of sand is recommended to extinguish such fires.

LEAD AND ITS ALLOYS

Lead enters into a number of engineering alloys, notably those used for solders and bearing metals.

Lead itself is a heavy metal with a silver-like lustre when freshly cut, very soft in character, but not very ductile or strong in tension. It has a specific gravity of 11·34, and melts at 327·4° C. Lead tarnishes readily on exposure to air.

Owing to its soft character it is easily worked, and as the film of oxide formed by atmospheric exposure acts as a protection against further corrosion, lead is much used for water pipes, gutters, sheathing, roofing, etc. It is very malleable, and can be beaten out into various shapes with ease.

Lead is one of the principal ingredients of the *softer bearing metals*, including lead-antimony alloys, certain Babbitt metals, and type metal.

Pure lead, although possessing excellent antifrictional qualities, is *not hard enough* for use alone in bearings, and becomes squeezed out of shape under pressure. It is hardened by adding antimony, tin, or copper. Lead-base alloys of this type are much used for slow-running and lightly-loaded bearings. The best lead-antimony alloy for bearings is that containing 80 per cent lead and the rest antimony ; it has a melting point of 260° C.

Another good bearing alloy consists of 85 per cent lead, 5 per cent tin, and 10 per cent antimony ; this is relatively hard and strong ; it is one of the Babbitt metals.

Lead-base bearing metals properly lubricated are capable of running at bearing pressures of 800 lb. per sq. in. without seizing, provided the working temperature does not exceed 80° C.

OTHER USEFUL LEAD ALLOYS

The table on the opposite page shows the compositions of some useful lead alloys, and includes the casting type metals, solders, and an expanding alloy for obtaining very sharp impressions of the mould.

If about 0·25 per cent of cadmium is included, with 0·5 per cent antimony or 1·5 per cent tin, the resulting lead alloys are much harder and stronger than ordinary lead, and pipes can be made appreciably lighter with these alloys.

Tellurium lead is another important alloy, containing up to 0·1 per cent tellurium. When this alloy is hammered or drawn it becomes both harder and stronger. Pipe and sheet are now made in this alloy in preference to pure lead.

TIN ALLOYS

Tin is used largely in connection with bronzes (in conjunction with copper) and in high-pressure type bearing metals. The effect of tin is to increase the toughness of lead, and, together with copper and antimony, it enters into the composition of the high-class whitemetals and bearing alloys.

One well-known Babbitt metal used for bearings consisted of tin, 80 per cent ; copper 10 per cent ; and antimony, 10 per cent. A much employed whitemetal used for lining the bearings of high-speed petrol engines and electrical machines consists of tin, 89 per cent ; copper, 4 per cent ; and antimony, 7 per cent. The best whitemetals are those containing the higher percentages of tin ; these have a fairly low melting point, and are as a rule expensive. The well-known Hoyt's bearing metals, Richard's, Admiralty, and

British Standard Institution Specification whitemetals are all of high tin content.

These whitemetals are used in bronze metal shells, primarily to prevent the metal from spreading, and also to provide a firm backing or support.

TABLE II

SOME USEFUL LEAD ALLOYS

Name	Lead	Tin	Other Constituents	Remarks
	%	%	%	
Tinman's or fine solder	37	63	—	Sometimes called blowpipe solder. Melts at 180° C.
Medium solder .	50	50	—	Largely used for tin-plate work.
Plumber's solder .	66·6	33·3	—	
Fusible alloy (Wood's alloy) . . .	25	12·5	Bismuth, 50 Cadmium, 12·5	Melts at 65·5° C. Used for wireless crystal seatings and steam boiler safety plugs.
Babbitt metal No. 7	63·5	20	Antimony, 15·0 Copper, 1·5	A useful bearing metal for medium pressures and speeds, or light pressure at a high speed.
Babbitt metal No. 6	48·5	40	Antimony, 10·0 Copper, 1·5	A useful bearing alloy for heavy pressures and medium speed. It is used for automobile engines, railway and tramcar bearings.
Babbitt metal No. 4	80	5	Antimony, 15·0	—
Type metal . .	70	—	Copper, 2·0 Antimony, 18·0	Used for cast type.
Stereotype metal .	82·0	3·2	Antimony, 14·8	For stereotyping.
Expanding alloy .	75	—	Antimony, 16·7 Bismuth, 8·3	This metal expands on cooling.

A typical copper-hardened tin-base alloy, known as Hoyt's No. 11, much used for petrol engine bearings, contains a high percentage of tin, has a compressive strength of 18 to 20 tons per sq. in., and a specific gravity of 7·34. It melts at 316° C. This is a plastic, yet tough, bearing metal. When bearing metals are chill cast in water-cooled metal moulds they become harder, of more uniform texture, and have superior wearing qualities.

NICKEL AND ITS ALLOYS

Nickel is an important metal in engineering work, not only as a protective material for brass and steel, but also when alloyed to other metals.

Nickel itself is a hard, white, silvery metal having a specific gravity of 8·8, and a melting point of 1427° C. It does not tarnish readily in air, and is capable of taking a high polish. Salt air causes slow corrosion of nickel, and the atmospheres of manufacturing districts are apt to cause tarnishing.

Another interesting point about nickel is that, like iron, it is magnetic. It has a fairly high electrical resistance, namely, about eight times that of copper.

Nickel in the wrought (annealed) state has a tensile strength of 18 to 20 tons per sq. in.; it is not very ductile, however.

Nickel is a valuable constituent of many of the more important alloy steels, notably in nickel steel (low and high nickel content), and nickel-chrome steel. When present in the proportion of about 25 to 35 per cent in steel, nickel gives it non-corroding and non-magnetic properties. An important feature of high nickel steel (35 per cent nickel) is that it is practically non-expanding, i.e. it has an extremely low coefficient of expansion. Invar steel, as used for clock pendulums, measuring tapes, and official standards of length, belongs to this class. It has only one-tenth the expansion (linear) of ordinary steel.

Alloys containing 47·5 per cent nickel and the rest iron have the same coefficient of expansion as glass and platinum, and wires of these alloys can be used for sealing in glass bulbs, such as electric light and wireless valve bulbs.

High nickel steel, on account of its non-corrosive properties, has been used for seaplane parts, exhaust valves of petrol engines, and boiler tubes. It is, however, being replaced in many of its applications by high chromium or " stainless steels."

Nickel may readily be deposited, by electro-plating, upon brass, bronze, or copper, and many copper alloys. Lead and most lead alloys, iron, and steel, and also aluminium require a preliminary copper-plating before nickel will adhere satisfactorily.

In copper-plating, a copper sulphate solution containing free acid may be used, but it is usual to employ a cyanide solution consisting of copper acetate, potassium cyanide, sodium sulphite, and sodium carbonate in water.

NICKEL-COPPER ALLOYS

Nickel forms an important series of alloys with copper; these have a wide field of industrial and engineering uses.

Copper containing about 2 per cent nickel is used for locomotive boiler parts such as boiler and flue tubes and stay-rods. It is much stronger than copper and withstands corrosion satisfactorily. Copper with 15 to 20 per cent nickel is used for the cases of bullets; the 25 per cent nickel alloy is used for coinage in many countries. The alloys containing 40 and 45 per cent nickel have high electrical resistances and are used for rheostats and resistances of all kinds; typical commercial alloys are Eureka, Ferry, and Constantan. Owing to their silvery appearance and non-corrosive properties these alloys are used for decorative purposes, such as counter fittings, spoons and forks, architectural decorations, door furniture, radiator shells, etc.

An important application of 15 per cent to 30 per cent nickel-copper is to steam engine condenser tubes on account of their excellent corrosion resistance and freedom from season cracking effects. Alloys containing more than 50 per cent nickel, including Monel metal, have excellent strength, ductility, and corrosion resistance; they are much used industrially for exposed parts, chemical plant, ships' fittings, and pump parts subjected to chemical action.

These alloys can be soft soldered and brazed satisfactorily, if suitable precautions are taken to eliminate the oxides by suitable fluxing. They are readily machined, the usual cutting speeds ranging from 30 to 100 ft. per min. according to the feed and depth of cut. These alloys are weldable by the usual gas and electric welding methods, using suitable welding rods and fluxes.

The so-called *nickel silvers* and German silver are alloys containing nickel, copper, and zinc; a typical example has 25 to 35 per cent nickel, 15 to 20 per cent zinc, and the rest copper.

MONEL METAL

This important alloy consists of about 68 to 70 per cent nickel, 26 to 28 per cent copper, and 3 to 5 per cent other constituents. It resembles nickel in appearance, and is strong, ductile, and tough. It is superior to brass and bronze in resisting corrosion, and has replaced these alloys for parts exposed to corrosive influences, notably for vats and linings in chemical works, for pump barrels, under-water valves, condenser fittings, sea-water exposed parts, and small marine propellers.

Monel metal has a melting point of 1360° C., and a specific gravity (cast) of 8·87. It weighs 0·319 lb. per cub. in. It has a tensile strength of about 25 to 30 tons per sq. in. (cast), and up to 40 tons per sq. in. in the drawn rod form.

Monel metal can be obtained in the form of castings, forgings, rods, bars, wires, bolts, nuts, washers, wire cloth, boat fittings, pump rods and liners, tube, stampings and pressings, etc. Monel metal is annealed by heating to 700° to 950° C.—according to the degree of softness required.

CHROMIUM

As this metal has, in recent times, come to the fore as a rival to nickel for plating metals to protect them against corrosion, it is proposed to mention a few of its properties of engineering interest.

Chromium is a steel-grey metal of an extremely hard nature—it is harder than glass and most hardened steels, and resembles corundum. It has a specific gravity of 6·92, and melts at 1550° C.

Apart from its use in small quantities in nickel-chrome and chrome-vanadium steels, and in larger quantities (up to 14 per cent) in "stainless" steel, chromium is now much used for plating steel, brass, and other copper alloys in order to provide protection against atmospheric corrosion. It is much superior to nickel, and does not tarnish. For this reason it is used to plate motor-car radiators, gudgeon pins, valve-lifters, and pump shafts. It gives an extremely hard surface—if plated sufficiently thick—and so is employed for coating the wearing parts of engineering gauges and measuring instruments.

On account of its low coefficient of friction, it can be used for coating the wearing parts of pins, bushes, etc.; it is employed on gudgeon pins of petrol engines for this reason. Further, as the plating is so hard, soft steel parts can be chromium-plated at a smaller cost than if heat-treated, high alloy steels, are used.

Chromium is more difficult to plate with than nickel, special precautions being necessary in the process. Further, it is from three to four times more expensive than nickel.

CADMIUM

Cadmium is a bluish-white, fairly soft metal of specific gravity 8·64, and melting point 321° C., that is now used for coating iron and steel articles subject to corrosive influences. It is used for plating aircraft and motor fittings, and although the surface does not remain bright, but becomes dull, the layer of oxide formed acts as a sure protection of the metal beneath. Polished surfaces can, however, be preserved by lacquering if desired.

SECTION IVB

CAST IRON AND WROUGHT IRON

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SECTION IVB

CAST IRON AND WROUGHT IRON

In consequence of the widely increasing use of metals in connection with all forms of engineering practice and workshop processes, it becomes increasingly important that engineers and metal workers generally should be acquainted with the varied properties of metals and the causes of their variation. For this reason, a careful study of the following pages should well repay the student or workman in obtaining a working knowledge of the inner structures of metals and their effect on the various physical properties. This treatment is only intended to be an introduction, as those who are particularly interested can follow it up by reference to several of the larger works on the subject.

CAST IRON

The term " cast iron " is used to denote the crude iron product obtained in a molten condition when iron ore is reduced with carbon.

In this manner it is distinguished from wrought iron, which is produced by the removal of most of the impurities of pig iron in a " puddling " or reverberatory furnace, and which is obtained in a forged condition. Mild steel or " ingot iron " differs from cast iron and wrought iron, being the refined product of the impure pig iron melted and worked down in a molten condition at higher temperatures, and cast in a pure condition in large ingots for subsequent rolling or forging.

Cast iron, although relatively very brittle and offering poor resistance to shock, possesses the virtue of being readily melted, and is capable of being cast in a sound condition into intricate shapes which maintain the pattern of the mould. In this is found its great sphere of usefulness to the engineering industry.

MANUFACTURE

Pig iron is obtained from the ore, which latter, after calcining, is charged along with coke and limestone into a vertical blast furnace of design similar to Fig. 1. The preheated air blast is introduced by the tuyères *t* at the bottom of the stack, and by partial combustion with the coke produces carbon-monoxide gas (CO), which on ascending through the heated charge brings about the reduction of the ore (iron oxide).

As the iron which is reduced in the upper and cooler parts of the blast furnace travels downwards, owing to the combustion and melting of the charge at the bottom, it becomes carburized by contact with the coke and reducing gases, so that on fusion it becomes saturated with carbon which it holds in solution.

Unfortunately for many purposes, other elements are reduced from the earthy matter in the ore. The function of the limestone is to remove by fluxing the greater amounts of these, which are then tapped off in the slag, but a small proportion of silicon from quartz, sand, etc., phosphorus from phosphates, sulphur from sulphates, etc., in the coke, together with manganese, is always absorbed by the liquid iron.

These form the common constituents of cast iron, and, with the exception of manganese, influence its properties to a degree not expected from the small proportions present.

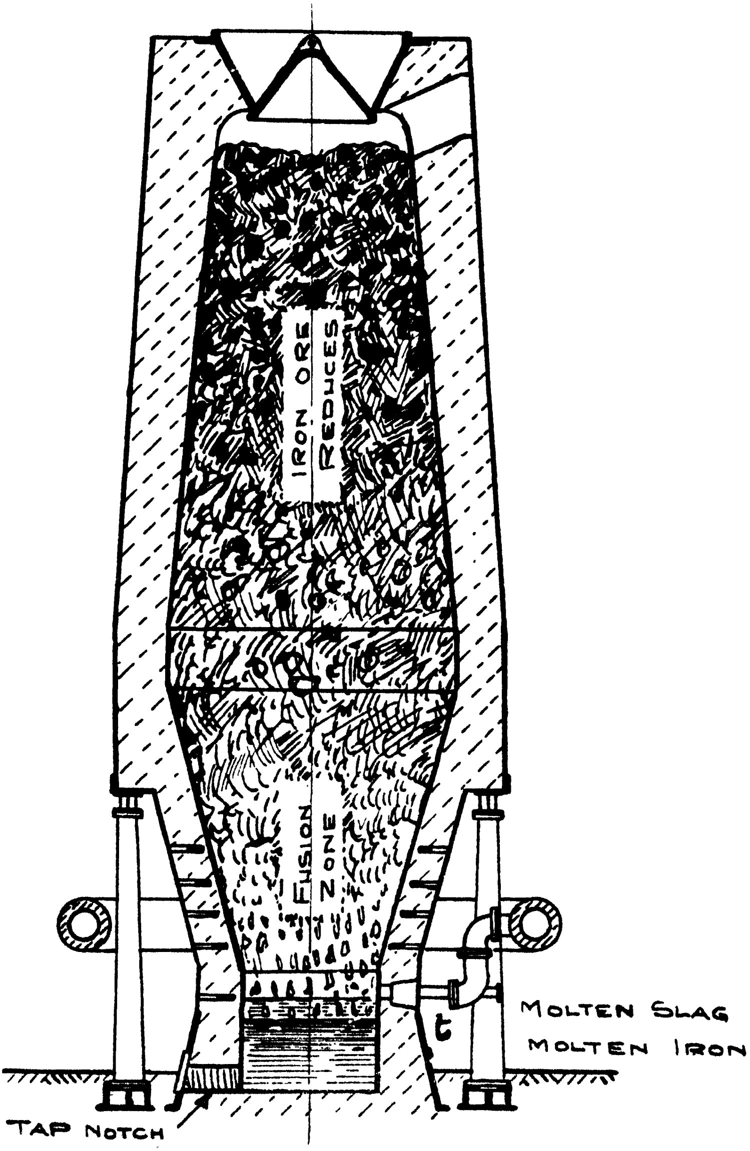
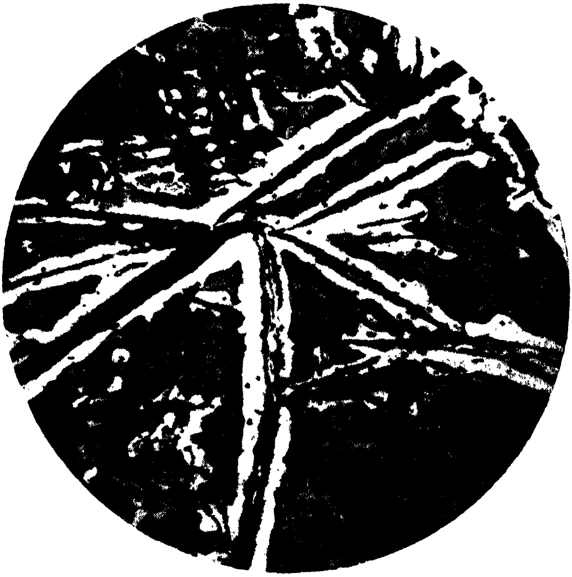


FIG. 1. DIAGRAMMATIC SKETCH OF BLAST FURNACE

It can be shown that a No. 3 foundry iron having the following composition—

Carbon	3·65%
Silicon	2·20%
Sulphur	0·08%
Phosphorus	1·57%
Manganese	0·60%
	8·10%

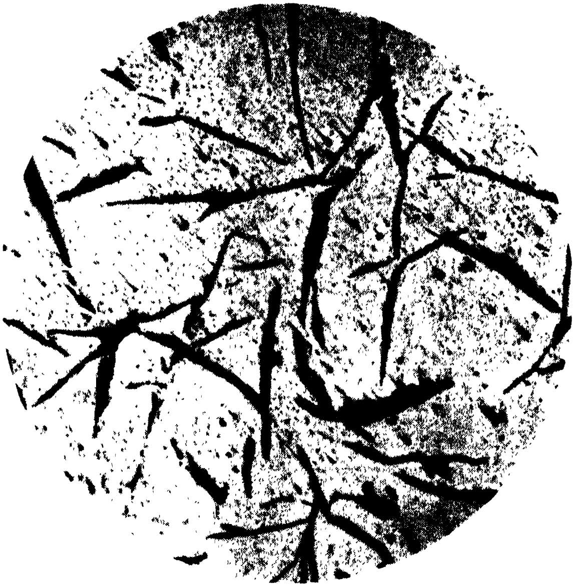


(*Magnified* 100 *diameters*)

FIG. 2. NO. 3 GRADE CLEVELAND PIG IRON
Graphite flakes, black ; ferrite, white ; pearlite, grey

contains about 60 per cent of its volume of compounds produced from the small total of 8·10 per cent. Referring to Fig. 2, we see that the free carbon (graphite) is in sectioned flakes or plates, traversing the matrix of silico-ferrite. The other constituents are pearlite (grey areas) produced by the combined carbon and phosphide of iron eutectic (white) running throughout the pearlite. Manganese is dissolved in the ferrite and pearlite matrix, and sulphur as sulphides is not shown at this magnification.

We have, therefore, to deal with the effect of varying proportions of these elements on the microstructure and physical properties of iron, and also trace their influence on the phenomena associated with freezing, and various rates of cooling.



(*Magnified* 50 *diameters*)

FIG. 3. LOW SILICON CAST IRON VERY SLOWLY COOLED

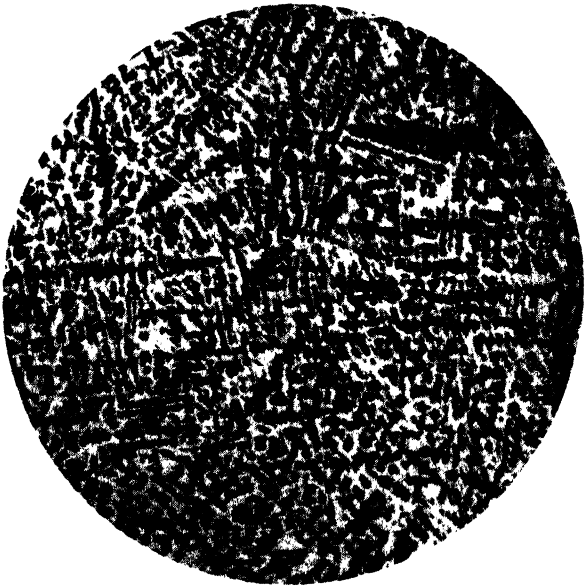
Showing complete separation of carbon as graphite flakes in a ground mass of ferrite (pure iron)

THE INFLUENCE OF CARBON

Pure liquid iron completely dissolves carbon, and if solidified and very slowly cooled the ultimate microstructure consists of pure ferrite (iron) and graphite, the carbon entirely separating as graphite, as shown in the photomicrograph, Fig. 3.

If the same iron is cast and cooled fairly quickly, either by chilling or by casting in a smaller section, a totally different alloy is obtained.

In the first case the cast iron is fairly tough, breaks with a dark glistening fracture, and is readily filed; whilst in the latter instance the iron is extremely hard, has a higher tensile strength, and breaks with a close white fracture. A micrograph of a typical white iron is shown in Fig. 4. The white constituent is in this case the very hard and brittle carbide of iron, known by the metallographic name of cementite. For the explanation of this phenomenon we must turn to the

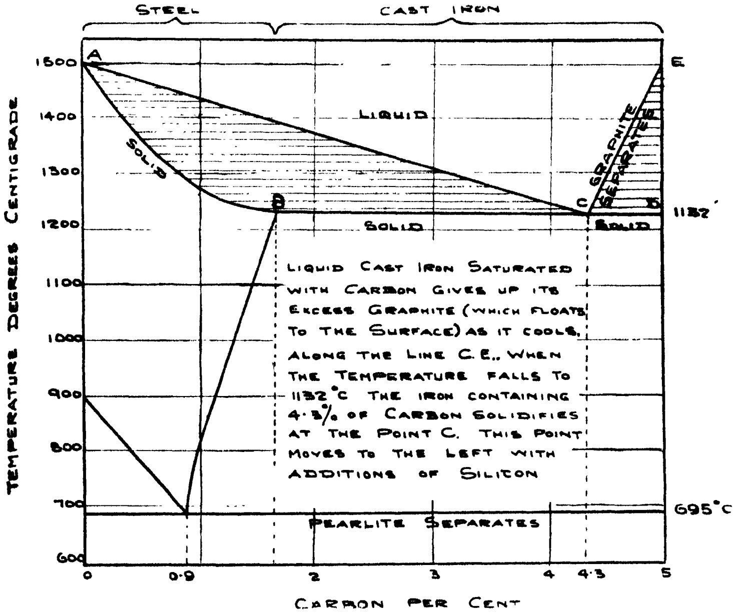


(*Magnified* 50 *diameters*)

FIG. 4. WHITE CAST IRON
Showing cementite

iron-carbon thermal equilibrium diagram, a simplified form of which is illustrated in Fig. 5.

In this diagram solidification commences when the temperature falls to the line *A*, *C*, *E*, and is complete when the line *A*, *B*, *C*, *D* is passed. The shaded areas denote conditions of partial solidification.



Liquid Cast Iron Saturated with Carbon gives up its Excess Graphite (which floats to the Surface) as it cools, along the line C. E.. When the Temperature falls to 1132°C the iron containing 4·3% of Carbon solidifies at the Point C. This Point moves to the left with additions of Siliton

FIG. 5. IRON-CARBON EQUILIBRIUM DIAGRAM

Iron, which is super-saturated with carbon from the blast furnace, throws out its excess of carbide which dissociates immediately to graphite along the line *C*, *E*. When the temperature has fallen to the point *C* a mixture of carbon and iron of constant composition freezes, this temperature being in the neighbourhood of 1130° C. The carbon content of this eutectic mixture is about 4·3 per cent pure white irons, but is lowered considerably by the introduction of silicon. Grey silicious irons of commerce usually, therefore, have a eutectic carbon composition for their given silicon content.

We have seen now that the first product of complete solidification is an intimate mixture of carbide of iron (cementite) and a solid solution. It is at this stage that the influence of the cooling rate (and of silicon and sulphur), as will be shown later, has its most marked effect: the iron may cool down from this point with but little change in structure, or the cementite may immediately break down and produce free graphite carbon.

The mechanism of this change has been the subject of much discussion, but it seems probable that the finely dispersed cementite of the eutectic mixture first coalesces and balls up into massive grains prior to dissolution into its constituent carbon and ferrite.

Three micro-sections of a chilled roll are reproduced in Fig. 6; (*a*) is from the chilled outer edge of the roll and shows a white iron structure, (*b*) is the mottled zone in which the cementite-graphite change has partially taken place. The massive nature of the cementite in the micrograph should be compared with that of the chilled edge. The grey iron from the centre of the roll is shown in (*c*), the structure consisting of graphite together with pearlite which separates from the solid solution of carbide and ferrite at the lower transformation point (695° C.), exactly as in the case of carbon steels.

These three micrographs illustrate clearly the varying nature of the material which can be produced by alterations in the rate of cooling of cast iron.

THE EFFECT OF SILICON

Silicon is the most important foreign element of cast iron. By its means the founder can control to a very fine point the separation of graphite and, therefore, the

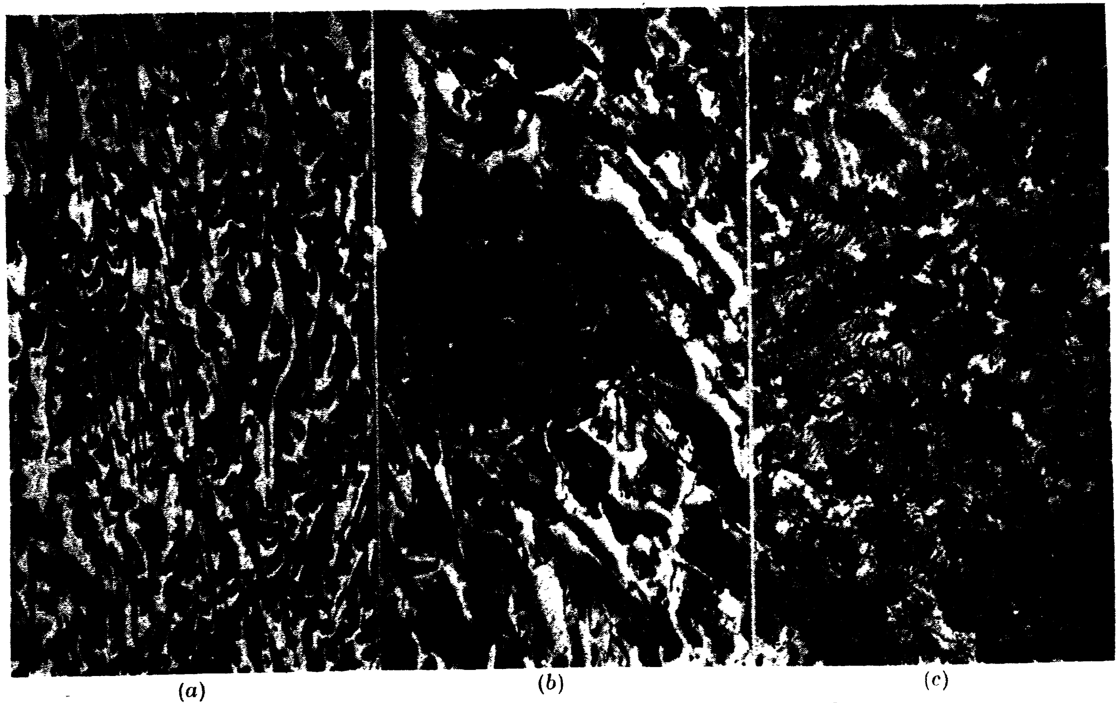


FIG. 6. THREE SECTIONS FROM CHILLED CAST IRON ROLL
(a) Chilled edge (b) Mottled zone (c) Grey centre

toughness and strength of the resultant product, over a wide range of sections.

It has, by itself, little effect on the hardness and ductility of *pure* iron when present in the proportions usually found in cast iron. In cast irons, however, it has a most marked effect in reducing the solubility of carbon in iron.

The following table, taken from Professor Turner's researches, illustrates the change in the condition of the carbon induced by increasing amounts of silicon together with the respective tensile strengths—

Total Carbon	Combined Carbon	Graphitic Carbon	Silicon	Tensile Strength Tons per Sq. In.
%	%	%	%	
1·98	1·60	0·38	0·19	10·1
2·00	1·90	0·10	0·45	12·31
2·09	1·85	0·24	0·96	12·72
2·21	1·71	0·50	1·37	14·04
2·18	0·56	1·62	1·96	15·70
1·87	0·68	1·19	2·51	14·62
2·23	0·80	1·43	2·96	12·23
2·01	0·20	1·81	3·92	11·28
2·03	0·37	1·66	4·74	10·16
1·86	0·38	1·48	7·33	5·34
1·81	0·69	1·12	9·80	4·75

These results were obtained on test bars of 1¼ in. diameter, and in this size of section the maximum strength is given with 1·96 per cent of silicon. Other physical properties obtained in the same series of experiments are shown diagrammatically in Fig. 7, and it will be seen that these follow each other very closely.

The analyses for combined carbon and graphite show clearly that the silicon exerts its beneficial influence by altering the condition of the carbon.

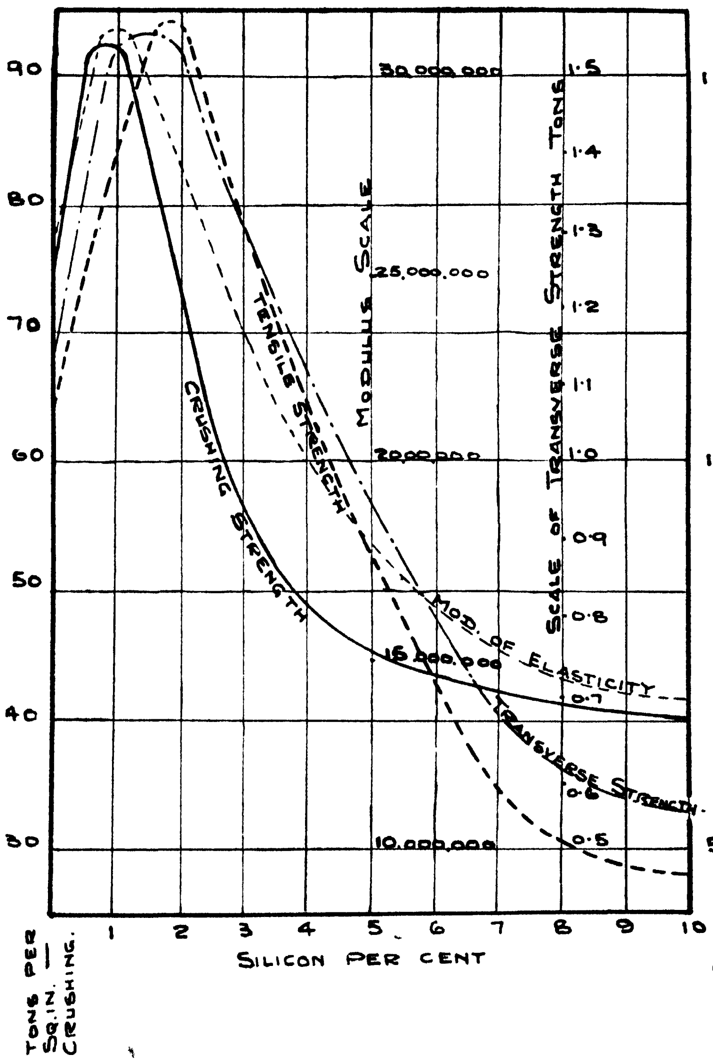


FIG. 7 VARIATIONS IN PHYSICAL PROPERTIES OF CAST IRON WITH INCREASING SILICON CONTENT

The effect of the breaking down of combined carbon (cementite) into graphite depends upon—

(*a*) The size of the casting.
(*b*) The casting temperature.
(*c*) The rate of cooling.

The size of the casting usually determines the rate of cooling, and whereas a small test bar containing under 1·0 per cent of silicon when cast will show a mottled or white structure, a large casting from the same metal will be quite grey.

Hatfield (*Journal of Iron and Steel Inst.*, 1906) describes two experiments to show the influence of casting temperature on the effect of silicon and the cementite-graphite transition. The first series was cast at normal temperatures in bars 1 in. by $\frac{3}{8}$ in. section. The results are shown in the following table, and diagram, Fig. 8—

Test No.	Series A (Cast at normal heat)							
	Analysis						Tensile Strength tons/sq. in.	Fracture
	Combined Carbon	Graphite	Silicon	Mn.	S.	Ph.		
	%	%	%					
7	2·9	Trace	0·28	Not exceeding 0·20 per cent	Not exceeding 0·05 per cent	Not exceeding 0·05 per cent	18·00	White
8	2·9	,,	0·53				22·80	,,
9	2·9	,,	0·63				14·50	,,
10	2·9	,,	0·66				13·40	,,
11	2·9	,,	0·88				17·40	,,
12	3·9	,,	0·99				18·10	,,
13	3·0	,,	1·10				16·00	,,
14	2·7	0·28	1·43				11·22	Trace mottled
15	2·3	0·65	1·68				11·40	Mottled
16	0·6	2·47	1·72				12·70	Grey
17	0·55	2·60	1·80				10·70	,,
18	0·55	2·68	1·96				14·90	,,
19	0·50	2·75	2·07				8·50	,,
20	0·50	2·75	2·19				15·60	,,
21	0·49	2·80	2·36				9·80	,,
22	0·48	2·85	2·50				9·06	,,

These figures show a rapid change from the combined to the free state at about 1·72 per cent silicon, results not obtained by other workers. The sudden transformation to graphite is probably due to the small section of the test bars employed, and a more gradual change might be experienced with larger sections.

Hatfield ascribes the peculiar variations in tensile shown in these tests to variations in the structural formation of the cementite. The high tensile samples when examined microscopically reveal a well-knit structure, whereas the low tensile samples show the cementite orientated in definite planes which might cause weakness.

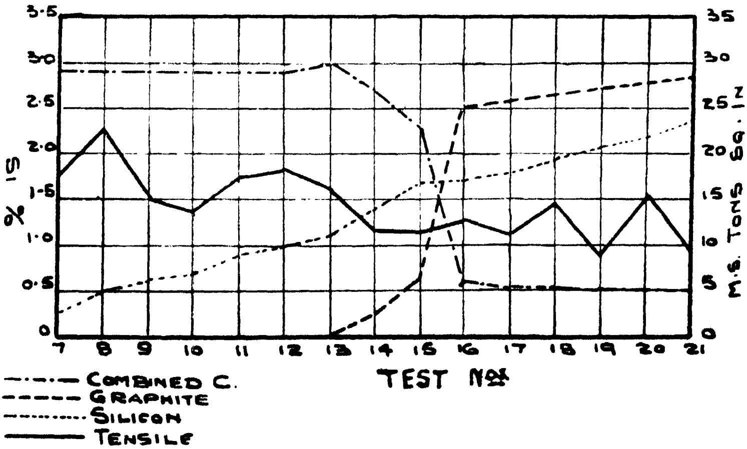


Fig. 8. Showing Change from Combined Carbon to Graphitic Carbon with Increasing Silicon Content

The influence of casting temperature is of importance to the founder, as metal which with normal conditions of temperature yields soft grey iron might easily, if the silicon content be rather low for the size of casting. give hard white or mottled iron difficult to machine and unsuitable for the job in hand.

GRADING OF PIG IRON

The foregoing figures have indicated the remarkable influence silicon possesses in controlling the relative proportions of combined carbon and graphite. The increasing proportion of graphite produced by additions of silicon is evidenced on the fractured pig by a coarsening of the grain, and a general darkening of the appearance of the surface at the fracture. A low silicon, low graphite, grey iron exhibits a close light grey fracture ; whereas a high silicon, high graphite, grey iron shows a dark, almost black, open crystalline condition.

This effect is readily understood when it is remembered that there is very little adhesion between the non-metallic graphite and the silico-ferrite surrounding it, so that fracture invariably takes place along these planes of weakness.

By examining the condition of the fractured surface, the iron-maker can immediately obtain an idea of the silicon content and place the pig in its appropriate class.

Various systems of classification are employed in different parts of the world and in some districts of this country, but the following method is the one most generally used and understood, the grade number, together with the approximate chemical analysis and Brinell hardness being as follows—

Grade No.	Combined Carbon	Graphite	Silicon	Sulphur	Phosphorus	Manganese	Fracture	Brinell Hardness No.
	%	%	%	%	%	%		
1	·300	3·750	2·60	·02	Variable	Variable	Open Grey	104
2	·450	3·500	2·30	·03			,, ,,	108
3	·550	3·200	2·00	·04			Finer ,,	112
4 Forge	1·000	2·800	1·60	·10			Fine ,,	160
4 Fo'dry	·75	2·100	1·05	·06			,, ,,	156
Mottled	2·000	1·600	·90	·20			Mottled	350
White	3·200	Trace	·65	·30			White	420

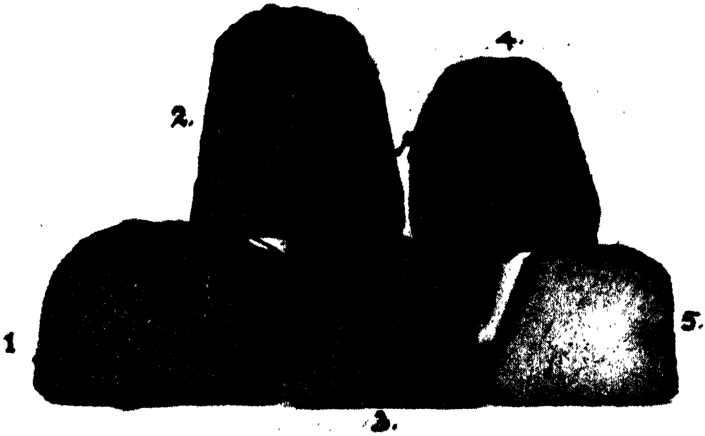
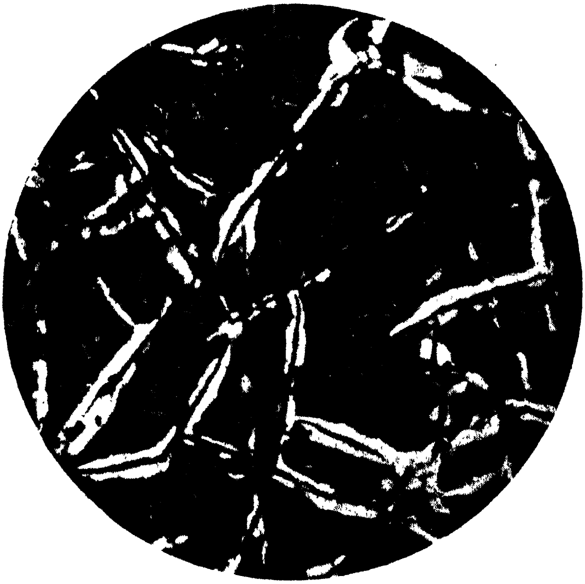


FIG. 9. TYPICAL PIG FRACTURES
1. No. 2 grade 2. No. 3 grade 3. No. 4 grade 4. Mottled
5. White



(*Magnified* 500 *diameters*)

FIG. 10. PIG IRON, GRADE NO. 2
Graphite, black flakes ; silico-ferrite, white ; pearlite, grey

Fig. 9 illustrates fractures of pig irons from various sources.

The microscopic structures are shown in Figs. 10, 11, 12, 13, and 14 ; a No. 1 grade pig being illustrated in Fig. 16. These show the gradual increase of combined carbon (pearlite and cementite) with decreasing silicon content. The free cementite, which exists only in Figs. 13 and 14, should not be confused with the phosphide of iron eutectic, which occurs in all photomicrographs except Fig. 10.

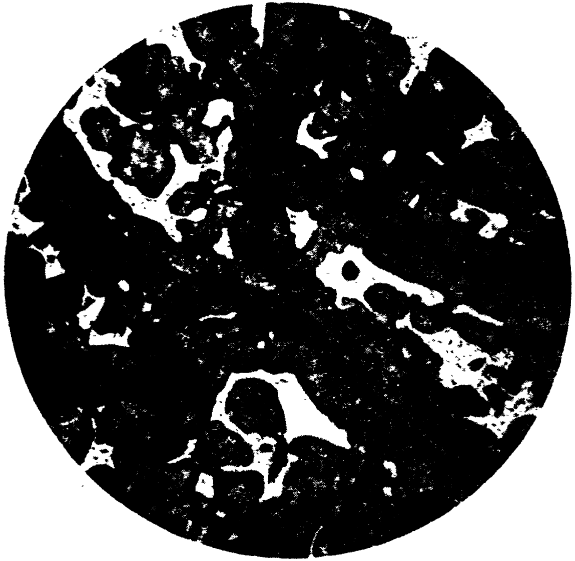
The tensile strength and resistance to impact increase with diminishing silicon content, and it is good practice to choose an iron with the lowest silicon content that will permit of easy work in the machine shop.

THE EFFECT OF SILICON ON SHRINKAGE

It is well known that cast iron, like other metals, occupies a smaller volume after cooling than the mould it is cast into. The usual works practice is to allow $\frac{1}{8}$ in. to the foot for contraction in grey castings, and about $\frac{1}{4}$ in. to the foot for white castings. The silicon content has a great influence on the ultimate amount of contraction.

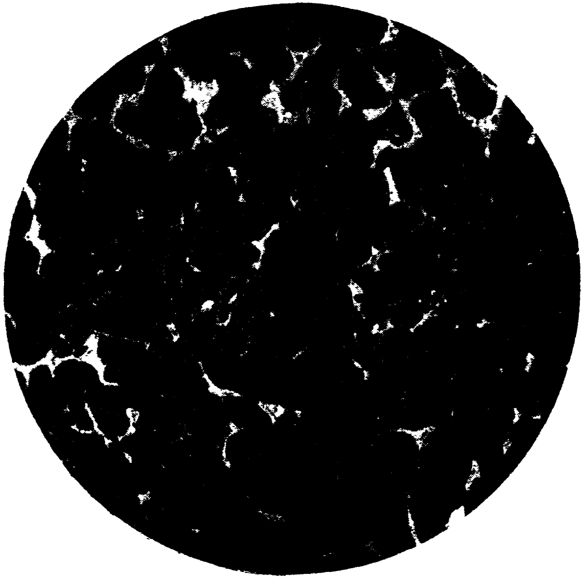
The results of measurements of volume changes during cooling on Northampton, grey hematite and a white iron are shown graphically in Fig. 15, compared with copper. These are taken from the extensometer experiments of Professor Turner (1906), and show that unlike copper, which cools uniformly, the cast irons show various expansions which modify the ultimate size of the casting, and have an important bearing on the question of soundness at the centre of the job.

The first expansion occurs immediately after solidification in the grey irons, and is due to the transformation of the cementite eutectic into graphite under the influence of silicon.



(*Magnified* 50 *diameters*)

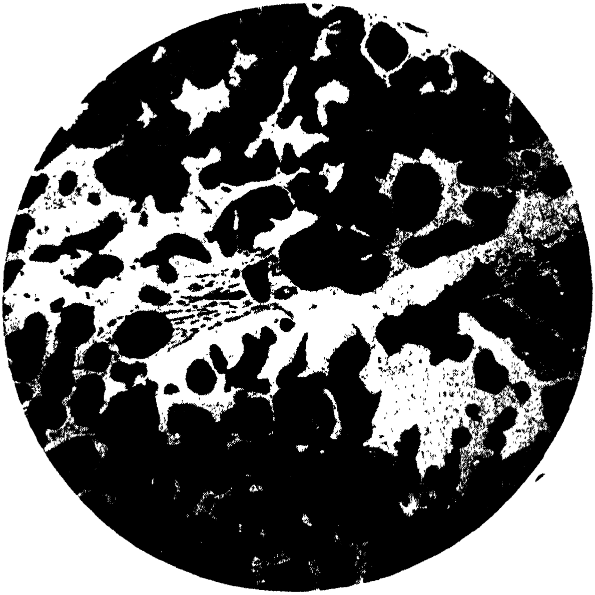
FIG. 11. PIG IRON, GRADE NO. 3



(*Magnified* 50 *diameters*)

FIG. 12. PIG IRON, GRADE NO. 4

The second expansion occurs only in phosphoric irons, of which the Northampton curve shown is typical, and takes place at a temperature slightly higher than 900° C. As will be shown later, this is due to the solidification and breaking down of the complex eutectic of iron, phosphorus and carbon.

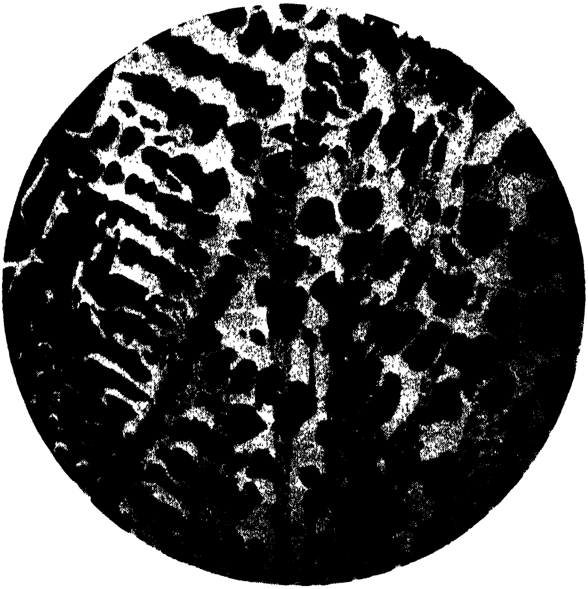


(Magnified 50 diameters)

FIG. 13. MOTTLED PIG IRON
Cementite, white

The third expansion, which is the most marked, occurs in silicious irons at the martensite-pearlite change point at about 700° C. At this point normal pearlite first separates and immediately is broken down under the influence of silicon, the cementite of the pearlite eutectic being transformed to graphite and silico-ferrite is thrown out in the free state. The curve for white iron shows a slight expansion at this point, owing to a slight precipitation of graphite which is usually found in the ultimate analysis.

The graphite produced by the two decompositions can be distinguished on the microscopic section. In Fig. 16 three forms of graphite are shown. This photomicrograph has been taken from a No. 1 grade high silicon pig, and shows the massive flakes of "kish" (carbon of super-saturation), curly graphite from the primary cementite change, and fine lamellar graphite from the pearlite decomposition.



(Magnified 50 diameters)

FIG. 14. WHITE CAST IRON
Cementite white

In Fig. 17, after Turner, is shown the contraction curve of a typical foundry mixture compared with a

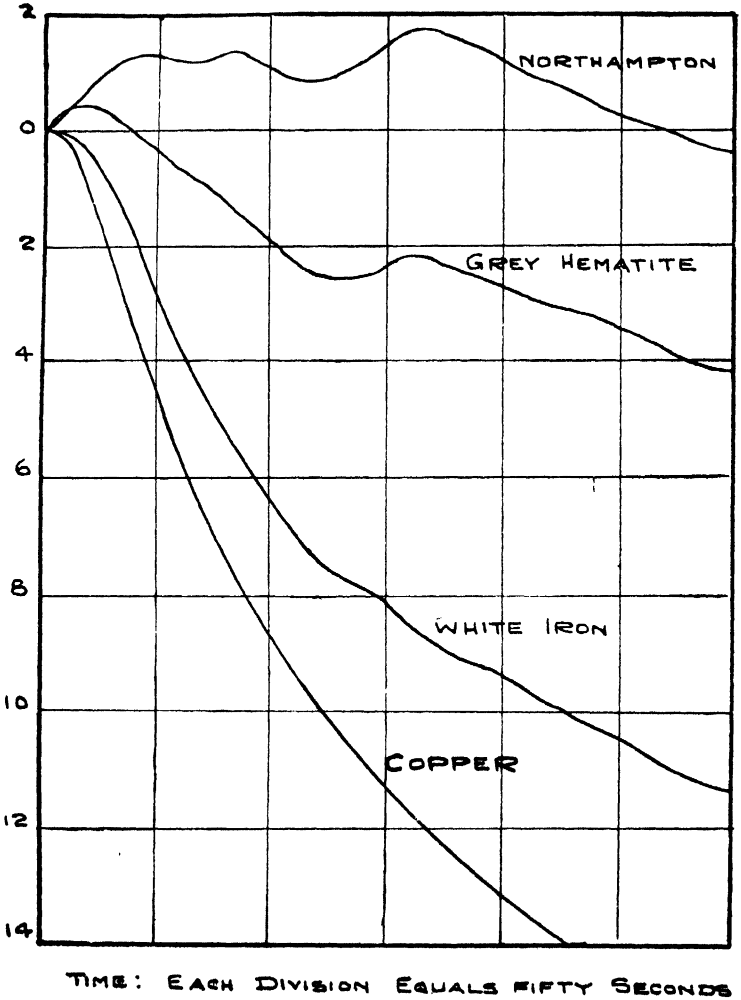
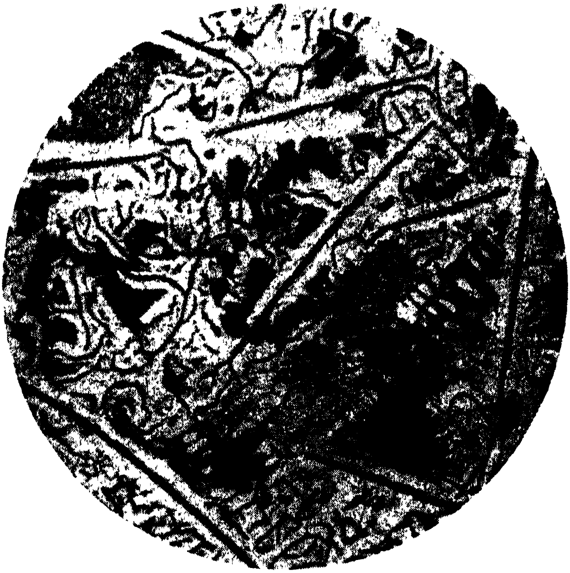


FIG. 15. SHOWING CHANGES IN VOLUME DURING COOLING

temperature recalescence curve taken at the same time.

The foundry mixture had the following analysis—

Combined carbon	0·79%
Graphite	2·73%
Silicon	1·41%
Sulphur	0·07%
Phosphorus	0·96%
Manganese	0·43%



(*Magnified* 50 *diameters*)

FIG. 16. NO. 1 GRADE PIG IRON
Showing three forms of graphite

The marked expansions of grey cast iron after solidification have a serious effect on the strength of castings which have been chilled. On account of the chilling, the casting takes externally the size of the mould. Subsequent internal expansions produce severe stresses on the chilled exterior which, being of white iron, has no ductility, and is not capable of elongating to any definite extent. It is therefore evident that the phosphorus content must be kept low to remove the expansion at 900° C., and that the silicon content be not high enough to produce the splitting up of the pearlite.

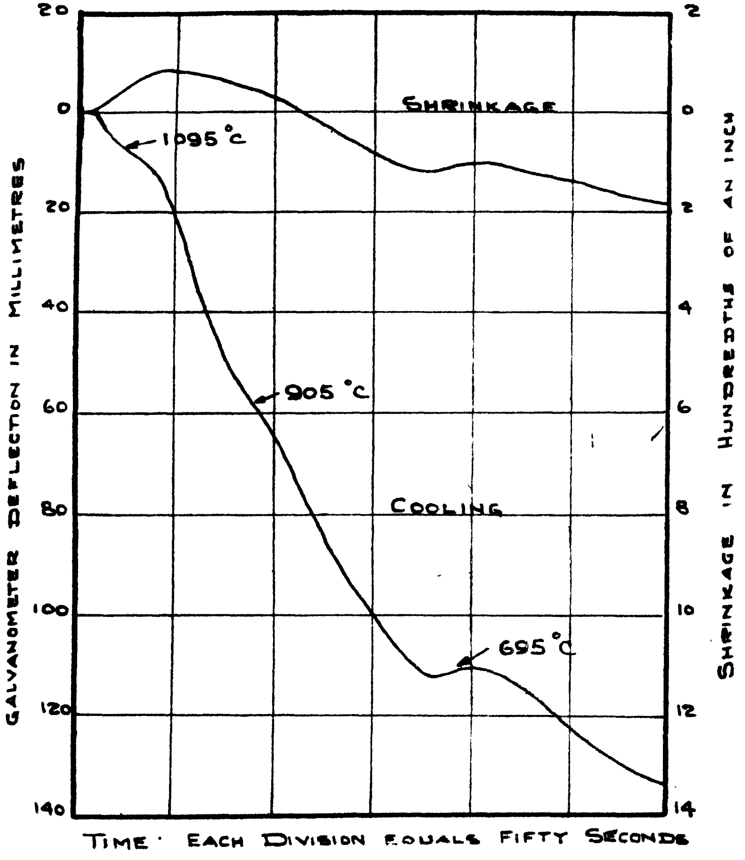


Fig. 17. Shrinkage Curve of Foundry Mixture Compared with Cooling Curve

Many failures of large chilled rolls have been traced by the authors to high phosphorus content, the rolls having failed immediately after putting into service.

THE EFFECT OF PHOSPHORUS

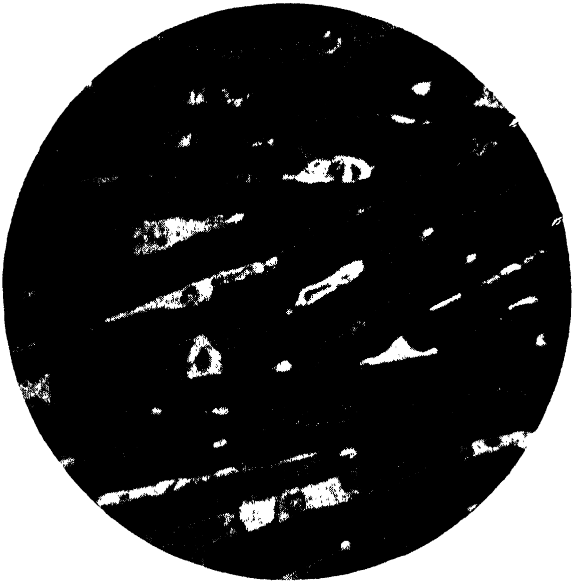
Phosphorus can be added to pure carbon-free iron in quantities up to 1·7 per cent without production of free phosphide of iron. The phosphorus is held in complete solution until the quantity present exceeds 1·70 per cent when free phosphide, Fe_3P, becomes noticeable under the microscope.

The free phosphide of iron freezes at about 950° C., and is the last portion of the casting to solidify. At this stage the eutectic consists of a mixture of iron, iron-carbide, and iron phosphide having a composition of about 6·7 per cent phosphorus and 2·0 per cent carbon. If silicon be present, the iron-carbide of the eutectic mixture immediately breaks down and forms graphite, leaving behind a structurally free phosphide of iron.

The addition of phosphorus has a marked effect on the fluidity of foundry irons, and it appreciably lowers the freezing point. Each 1·0 per cent of phosphorus is said to lower the initial freezing temperature by 27° C. This is a great advantage to the foundryman, and it is well known that by the aid of phosphorus small intricate castings can be cast at a lower temperature, the sharpness of the pattern being maintained in a manner impossible with phosphorus-free irons, but free phosphide imparts a distinct brittleness to the casting owing to the manner in which it divides up the silico-ferrite matrix. This effect is, however, largely overshadowed by the preponderating effect of the graphite flakes.

THE EFFECT OF SULPHUR

The amounts of sulphur found in grey siliceous irons are usually small, and have no noticeable effect on the strength and nature of the casting. It is usually found associated with manganese as small globules of manganese-sulphide distributed throughout the mass. It is an established fact that the sulphur content increases with decreasing silicon content, and, if much sulphide is present in low silicon irons, it has a tendency to retain the iron in the white condition.



(*Magnified* 1000 *diameters*)

FIG. 18. CEMENTITE BLACK, AND SULPHIDE WHITE, IN HARD MALLEABLE CASTING

Fig. 18 is a micrograph, magnified 1000 times, taken from a hard and brittle malleable iron casting. The micro-section has been heat-tinted, during which operation the cementite is coloured a dark brown and the sulphide is trapped between the cementite plates of the original eutectic, and has apparently been the cause of the failure of the cementite to break down to amorphous or temper carbon during malleablizing.

THE EFFECT OF MANGANESE

Manganese is rarely found in normal cast irons in quantities greater than 2·0 per cent. Apart from the beneficial effect of combining with the sulphur present and neutralizing its effects, it introduces no marked changes in micro-structure or casting properties. The addition of small amounts of manganese appears to be beneficial to tensile strength and toughness.

THE EFFECT OF NICKEL

Nickel is one of the more important elements in modern alloy cast irons and its addition in small amounts up to about 2 per cent imparts certain advantages which may be summarized, briefly, as follows; It (1) refines the grain; (2) reduces porosity; (3) increases both the tensile strength and hardness; (4) produces more uniform castings in the case of more complicated shapes; (5) reduces and controls the chill.

In regard to its effect upon the strength properties of cast iron, nickel addition to grey iron having 3·1 per cent carbon and 2 per cent silicon has the beneficial effects shown in the following table—

EFFECT OF NICKEL ON STRENGTH OF GREY CAST IRON

Percentage of Nickel	Transverse Strength (tons per sq. in.)	Tensile Strength (tons per sq. in.)	Compressive Strength (tons per sq. in.)
0	1·52	10·0	33·5
0·5	1·78	13·7	35·8
1·0	1·96	14·5	37·6
1·5	1·99	14·6	40·0
2·0	1·98	14·5	42·5

Nickel also increases the hardness without impairing the machinability in a somewhat similar manner to silicon, by hardening the iron matrix and producing sorbite instead of by an increase in the carbides.

Another important property of nickel is that of increasing the wear resistance of cast iron. For this reason automobile and steam engine cylinders of nickel cast iron have from two to three times the useful wear life of plain cast-iron ones, before reboring becomes necessary. The finer structure and absence of brittle iron carbide particles, which when dislodged by abrasion tend to score the surfaces, are the primary causes of the increased wear resistance of nickel cast iron. A typical analysis of such an iron, as used for automobile cylinders, is as follows: Total carbon, 3·35 per cent; manganese, 0·6 per cent; sulphur, 0·08 per cent; phosphorus, 0·08 per cent; nickel, 1·30 per cent; chromium, 0·45 per cent, and silicon, 2·20 per cent.

The usual Brinell hardness number of such nickel cast irons varies from 200 to 250.

THE EFFECT OF CHROMIUM

When small percentages of chromium are added to cast irons of suitable compositions, the combined carbon is increased and the mechanical strength and hardness are improved. Chromium, however, is generally used in cast iron in association with nickel, the usual ratio of chromium to nickel being 1 to 3. In these proportions it has the effect of opposing graphite formation and stabilizing the carbon, the resulting structure being one of *pearlite-cementite* or *martensite-cementite*. It is undesirable, however, to employ more than about 0·5 per cent of chromium, as greater proportions result in the formation of hard areas of chromium carbide in the iron which render the metal difficult to machine.

When extremely hard chill castings are required a suitable composition is a cast iron containing 3·0 per cent carbon, 4·0 per cent nickel, and 1·5 per cent chromium. This gives a deep chill of martensite-cementite structure.

THE EFFECT OF MOLYBDENUM

The addition of small amounts of molybdenum, in association with low nickel and chromium content in cast iron, results in a toughening and increase in the strength of the metal. It also promotes a more uniform grain of finer texture and retards grain growth. For these reasons molybdenum cast irons are particularly suited to the making of castings of intricate form and to those having sections of varying thicknesses. The tensile strength is increased with the increase of molybdenum up to 1·5 per cent. Thus, in the case of a plain cast iron having a tensile strength of 11 tons per sq. in., the addition of 1·5 per cent of molybdenum gave a tensile strength of 19 tons per sq. in. and a similar percentage increase in the transverse strength.

Molybdenum cast irons are sounder and more machinable than plain irons and are particularly suited to the making of automobile engine cylinder blocks, heavy machine tool castings where high strength and wear resistance are required, pipes, ingot moulds, and pressure castings. Chilled iron rolls of molybdenum cast iron are now used for steel rolling mills and for rolls employed for brass, bronze, and copper. The following is the composition of a high-strength cast iron having a tensile strength of 22 tons per sq. in. and Brinell hardness of 230: Total carbon, 3·2 per cent; combined carbon, 0·7 per cent; manganese, 0·6 per cent; phosphorus, 0·27 per cent; sulphur, 0·09 per cent; silicon, 2·0 per cent; molybdenum, 0·4 per cent; chromium, 0·2 per cent.

THE EFFECT OF COPPER

Copper is employed in certain modern cast irons, in association with chromium, nickel or molybdenum, and yields a range of high-duty irons having many important applications. It has a mild graphitizing action and toughens the matrix of the iron. Copper cast irons are particularly applicable to automobile and pressure castings as they give light sections free from chill effects and at the same time a close structure in the thicker sections. When used to replace silicon, copper increases the strength of the metal, promotes uniformity of structure, and balances the chilling influence of certain other elements such as manganese, chromium, and molybdenum, which might otherwise cause brittleness.

The following is the composition of a high-duty cast iron containing copper, which has a tensile strength of 27·8 tons per sq. in. and a Brinell hardness of 299: Carbon, 2·85 per cent; silicon, 1·61 per cent; copper, 1·90 per cent, the remainder being iron.

AUSTENITIC CAST IRONS

These cast irons contain larger proportions of elements such as nickel, copper, and manganese, which give to them an austenitic structure and thereby impart important heat- and corrosion-resistance properties. Special irons in this class include those known as "Nomag" (non-magnetic cast iron), "Ni-Resist," and "Nicrosilal," which are much used in industry; these irons are referred to more fully later in this section. Austenitic irons possess medium tensile strength and have greater ductility than grey cast iron. They also have a greater impact strength and a higher coefficient of linear expansion, with lower thermal conductivity value.

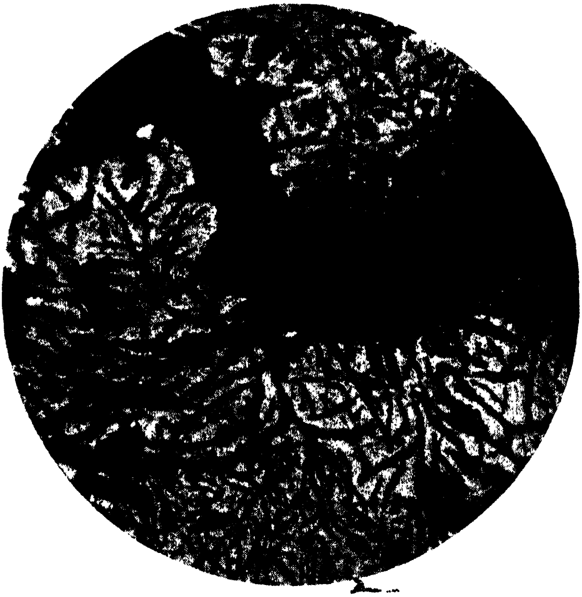
CRANKSHAFT CAST IRONS

Special cast irons of recent development are now employed for making crankshafts and camshafts of petrol and Diesel engines. A typical low carbon alloy cast iron having only 1·75 per cent of carbon and containing 0·6 per cent manganese, 1·95 per cent nickel, 0·65 per cent molybdenum, and 0·6 per cent silicon, which has been used for the crankshaft of a heavy oil engine, was heat-treated to give a tensile strength of no less than 63 tons per sq. in. with 1 per cent elongation and a Brinell hardness of 375. It will be seen that this strength value is as good as that of a medium tensile alloy steel, but the ductility—as shown by the relatively low elongation value—is considerably less than for this steel. The alloy cast iron was heat-treated by heating it to 1000° C. and cooling in air. It was then tempered by heating it to 550° C. and cooling in air. Other alloy cast irons used for crankshafts include copper-chromium irons, nickel-chromium irons, chrome-molybdenum and inoculated irons.

The well-known Ford Vee-eight engine crankshafts are of a special cast iron of the copper-chromium class, containing 1·25 to 1·40 per cent carbon; 1·9 to 2·0 per cent silicon; 0·5 to 0·6 per cent manganese; 2·5 to 2·75 per cent copper; and 0·35 to 0·40 per cent chromium with extremely small proportions of phosphorus and sulphur.

The use of a casting instead of a forging enables an appreciable saving to be made in manufacture. Thus a typical cast crankshaft weighed 65 lb. before machining and 56 lb. after machining. The previously used forged steel crankshaft weighed 90 lb. before and 66 lb. after machining, so that the cast crankshaft was not only 10 lb. lighter but required the removal of only 9 lb. of metal during machining as compared with

24 lb. for the forged steel one. Moreover, only 54 operations were necessary in the manufacture of the cast-iron crankshaft as against 62 for the forged one. The cast-iron crankshaft had a Brinell hardness of 300 and it had a better wear resistance than the steel crankshaft.



(*Magnified* 50 *diameters*)

FIG. 19. SECTION OF "GROWN" CAST-IRON ANNEALING POT

Showing oxide formation along graphite flakes

GROWTH OF CAST IRON AFTER REPEATED HEATINGS

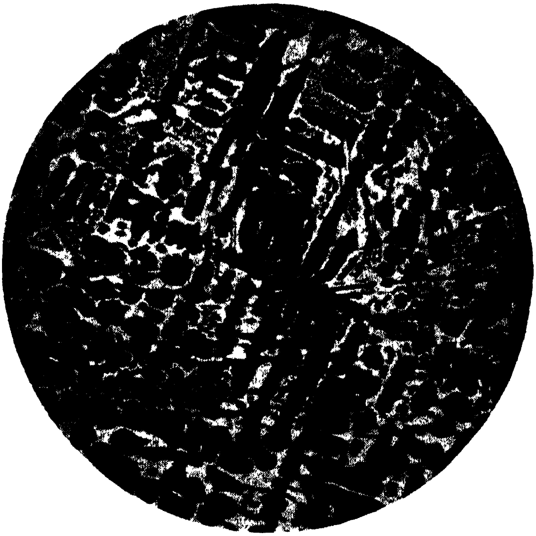
The growth of grey cast irons after repeated heatings has had much attention from engineers and metallurgists in the past. The phenomenon of growth is evidenced when grey cast iron parts are subjected to high temperatures, and although the iron increases in size more rapidly if the heatings are intermittent, marked increase in size, volume, and weight is conferred on prolonged heating at temperatures in excess of 650° C. In all cases where growth has taken place the phenomenon is accompanied by a pronounced deterioration of mechanical and physical properties. Hence, attempts made to increase the size of castings cast too small, to permit of subsequent use, should be strongly discouraged.

The micrograph (Fig. 19) is taken from a portion of a large cast-iron annealing pot which had been subjected to many heatings at a temperature of about 750° C. This had cracked badly in service, and was found to be in an unsound condition. The graphite flakes were found to have swollen appreciably in size and in many places had given place to deep fissures filled with " scale," one of which is shown in the photograph. The cause of growth is now known to be due to the entry of oxidizing gases along the weak planes of the graphite flakes. The graphite is readily oxidized to gaseous CO_2, leaving fissures which become filled with scale (Fe_3O_4). The siliceous ferrite continues to oxidize as long as heating continues, and as the resultant oxide so formed has a greater volume because of its oxygen component, the mass of the iron is forced open, and the casting swells just like a sponge which has absorbed water. If the heating is intermittent, the expansion and contraction of each heating and cooling operation produce fissures more readily owing to the poor adhesion between graphite and the surrounding metal. Disintegration ultimately takes place.

MALLEABLE CAST IRON

The rapid growth of the malleable castings industry of recent years, particularly in America, bears testimony to the usefulness and value of this material for small parts where strength and ductility are essential.

Small castings of grey cast iron are by virtue of their thin section very weak and brittle, and the difficulty of casting steel in small sections rules this material out of the question. The ease with which iron can be cast into small sections and then malleablized on mass production lines has placed a very useful metal in the hands of the engineer.



(*Magnified* 100 *diameters*)

FIG 20. WHITE IRON CASTING BEFORE MALLEABLIZING OR ANNEALING

The manufacture of malleable iron can be divided into two parts: (1) the Whiteheart or Réaumur Process, and (2) the Blackheart or American Process.

The starting product in each case is white cast iron low in sulphur and phosphorus. After casting to the required shape, the resultant white casting, which is very hard and brittle is, in the Réaumur process, packed in oxide of iron and heated to a temperature of about 1000° C. for four days and then slowly cooled. The resultant casting becomes decarburized somewhat deeply, but in the centre the carbide of the white cast iron breaks down to amorphous or "temper" carbon, which is found aggregated into small pockets, leaving a matrix of more or less pure ferrite or pearlite. The soft and powdery "temper" carbon has little effect on the tensile properties other than reducing slightly the effective cross-sectional area of metal, and the casting produced can be readily machined and has a good bending angle. The micrograph (Fig. 20) is from a white casting before malleablizing, and in Fig. 21 is shown a portion of the subsequent malleable iron.

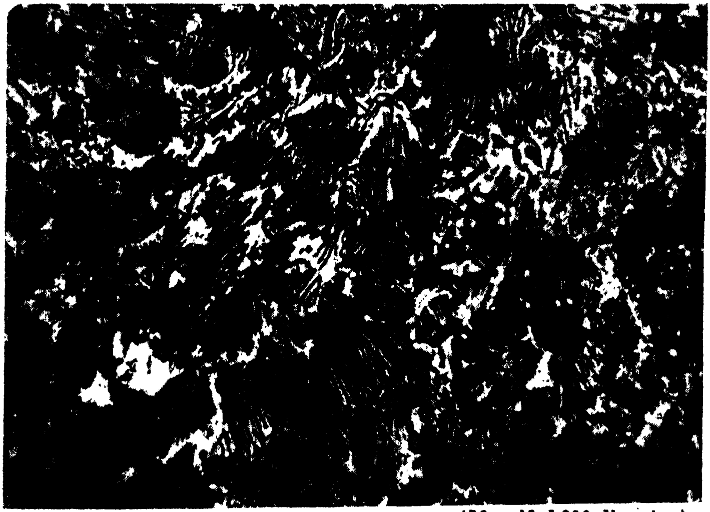
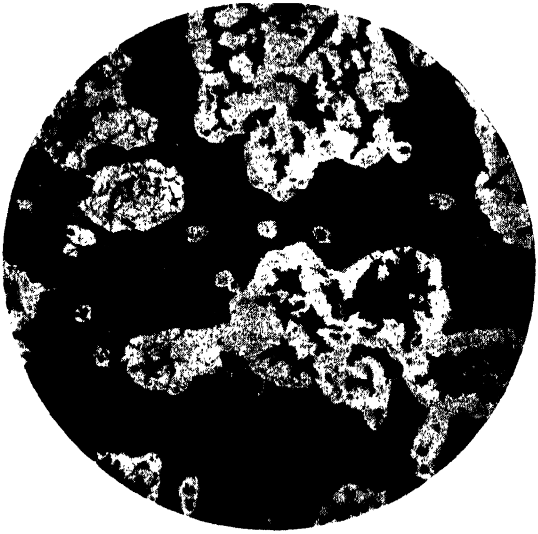

(Magnified 200 *diameters)*

FIG. 21. CENTRE OF WHITEHEART MALLEABLE CASTING

The structure consists of temper carbon (black spots) in a matrix of pearlite

In the blackheart process, the white casting is heated for some hours at a lower temperature than in the

Réaumur process, being between 850° C. and 900° C. The castings are not packed in an oxidizing medium and, consequently, the decarburizing is only superficial. The centre of the casting contains "temper" carbon which imparts a black appearance to the fracture, hence its name.



(*Magnified* 100 *diameters*)

FIG. 22. AMERICAN "BLACKHEART" IRON

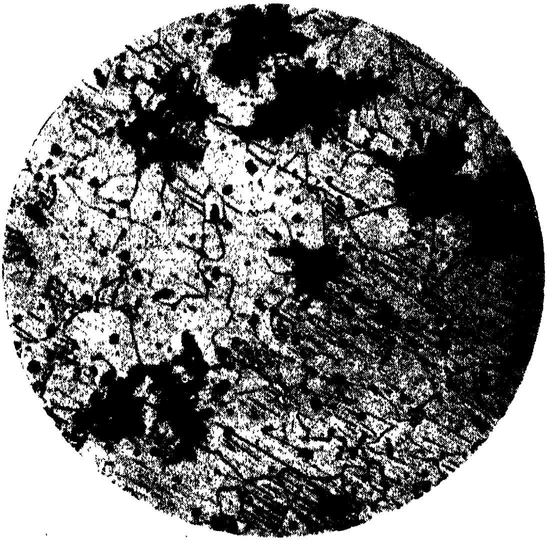
Temper carbon, black; ferrite, white; pearlite, matrix

The following analyses show the changes which take place due to this treatment—

	Combined Carbon	Graphitic Carbon	Silicon
Before annealing .	2·60	0·72	0·71
After annealing .	0·82	2·75	0·73

The micro-structure of a typical American blackheart iron is shown in Fig. 22.

English "blackheart" practice differs slightly from American as the period of annealing is rather longer, no pearlite being visible on the micro-section. The micro-structure consists of practically pure ferrite, in which are embedded the patches of "temper" carbon as shown in Fig. 23. The tensile strength is slightly lowered, but increased ductility and better machinability are obtained.



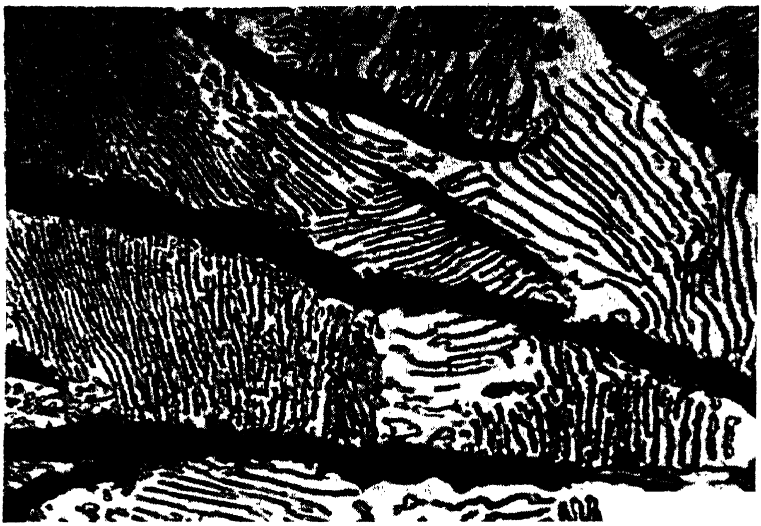
(Magnified 100 *diameters)*

FIG. 23. ENGLISH "BLACKHEART" IRON

The temper carbon is embedded in soft ferrite; pearlite entirely decomposed

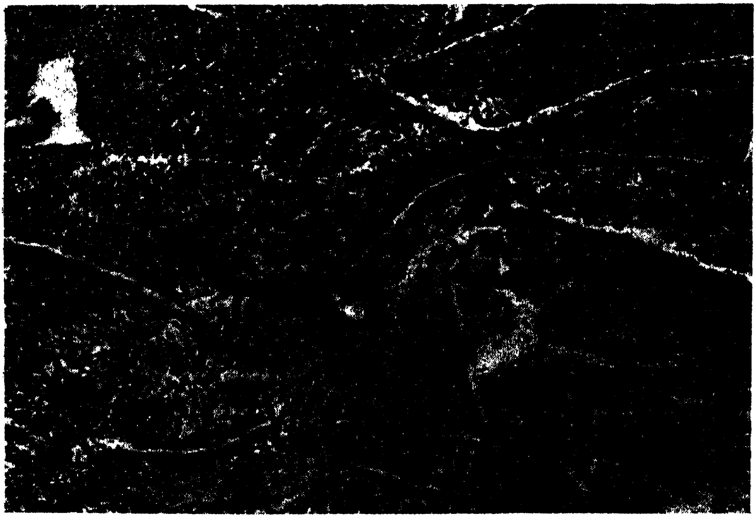
SPECIAL CAST IRONS

Considerable progress has been made during the last few years in the production of high tensile but malleable grey cast irons. These are usually low in silicon, but special attention has been paid to the control of the cooling rate, either by heating the moulds or by casting particularly hot to attain the same ends. By



(*Magnified* 500 *diameters*)

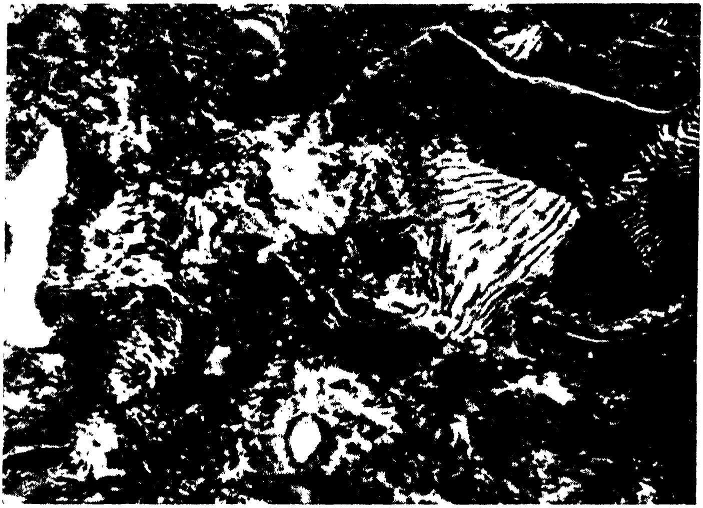
FIG. 24. GRAPHITE AND PEARLITE IN HIGH TENSILE CYLINDER LINING (" LANZ " PROCESS)



(*Magnified* 500 *diameters*)

FIG. 25. CURLY GRAPHITE AND SORBITE IN HIGH TENSILE CAST IRON

these means the casting produced, although low in silicon, is grey in character and the micro-structure is pearlitic or sorbitic (a tougher form of pearlite) through which the graphite runs in a fine flake. Such a condition is obtained in the "Lanz" process, and is illustrated in Figs. 24 and 25. By this process a tensile strength of 18 tons per sq. in. can be obtained with remarkably good bending properties.



(*Magnified* 500 *diameters*)

FIG. 26. HIGH TENSILE CASTING, "EMMEL THYSSEN" PROCESS

Tensile strength, 26·9 tons per sq. in.

The "Emmel Thyssen" process, in which the metal is cast hotter than normal, produces a casting containing the graphite in a very fine curly form as illustrated in Fig. 26. The casting from which this micro-section was taken yielded a tensile strength of 26·9 tons per sq. in., and the physical properties generally represent an advance over the earlier "Lanz" method. These processes are covered by various patents.

The authors are indebted to Mr. J. S. G. Primrose for the loan of Figs. 16, 21, 24, 25, and 26, and for his help in correcting the proofs.

Another much-used special iron is that produced by the Meehanite process whereby the low carbon cast iron used is rendered grey from the white or mottled condition by the addition of a carbon-free silicide. These irons normally have tensile strengths of 20 to 23 tons per sq. in. and hardnesses up to 500 Brinell. There are, however, several grades of Meehanite cast iron with tensile strengths ranging from about 13 up to 33 tons per sq. in. and hardnesses of 140 to 600 Brinell.

INOCULATED CAST IRON

This grade of cast iron is an improved metal made by crushing the silicon ore and introducing it to molten cast iron and scrap, instead of melting these ingredients together. This method gives plain cast irons of higher tensile strengths and avoids white or mottled regions in the irons, which in practice are near the margin owing to low carbon or silicon contents: it enables cast iron to be made with lower carbon and silicon content without being too hard but giving higher tensile strength. It is based on the idea of adding a graphitizing element to a cast iron which would normally be white or mottled. Actually, the Meehanite irons previously mentioned are of the inoculated class. Such irons are used for engineering castings where high stresses occur or where reduced sections are required and ductility is not of primary importance.

LODED CAST IRON

This is a pearlitic cast iron having no ferrite, with a high silicon content, namely, from about 2·5 to 7·0 per cent. This type of cast iron possesses great stability under high temperature conditions, good bearing metal qualities favouring the holding of the oil film upon the bearing surfaces. It is also resistant to the attack of corrosive acids, the resistance increasing with the percentage of silicon and chromium in the iron. It possesses a medium tensile strength, namely, about 17 tons per sq. in. Owing to these qualities and to the further advantage of being able to form quickly in a skin which strongly resists wear, such cast irons are much used for cylinder castings of hydraulic, steam, and internal combustion engines instead of the usual plain cast irons. Most of the loded cast irons thus employed contain from 4 to 6 per cent of silicon and 1 to 4 per cent of chromium; the exact proportions of the latter element are adjusted to the silicon content to give the "all-pearlitic" structure.

HOT MOULD CAST IRONS

These irons have a medium carbon but low silicon content and are produced in heated moulds which delay the rate of cooling. The proportion of silicon used is adjusted for the selected temperature of the mould so as to give a uniform all-pearlitic structure for every shape and size of casting made by this process. Thus, for thick sections of casting the silicon content is a minimum, whereas for thin sections it is a maximum. The mould temperature usually ranges from 400° to 500° C. The hot mould irons give tensile strengths of 14 to 18 tons per sq. in. They are used for the cylinders of steam and Diesel engines, cylinder heads, liners and pistons, turbine casings, bedplates, etc. A typical composition for a hot mould cast iron is as follows: Total carbon, 3·0 per cent; combined carbon, 0·74 per cent; silicon, 0·46 per cent; manganese, 1·15 per cent; sulphur, 0·11 per cent; phosphorus, 0·14 per cent.

Typical commercial hot mould irons are those of Lanz, previously mentioned, and Diefenthaler.

"NOMAG" CAST IRON

This is a non-magnetic cast iron developed by Messrs. Ferranti Ltd., and was produced by additions of nickel and manganese in relatively large amounts to an ordinary cast-iron mixture. Nomag is used on account of its non-magnetic properties for castings employed in electrical work, such as alternator end rings and plates, busbar chambers, alternator coil supports, transformer covers, etc. It has a tensile strength of 9 to 11 tons per sq. in. and a transverse strength about 12 per cent higher than for grey cast iron. It can readily be cast into difficult shapes and has a rather greater shrinkage than grey cast iron, namely $\frac{3}{16}$ in. per foot as against $\frac{1}{8}$ in. per foot. It can be machined readily, but is tougher in this respect than mild steel. Nomag has a rather higher heat expansion coefficient than grey cast iron, namely, about 13 per cent more.

"NI-RESIST" CAST IRON

This is a special alloy iron belonging to the austenitic iron class with very good corrosion- and heat-resistance properties. It contains from 13 to 16 per cent of nickel, 6 to 8 per cent copper, and 2 to 6 per cent of chromium; the carbon content is 2·6 to 3·2 per cent. It has a very much higher resistance to corrosion attacks by acids and gases than ordinary irons; it is also at least four times as resistant to sea-water corrosion as ordinary cast iron. It has excellent heat-resisting qualities, not only on account of the resistance to oxidation but also because the amount of combined carbon usually found in the metal is low and no structural change takes place on heating. It retains its mechanical strength properties at higher temperatures much better than ordinary cast irons. It has a tensile strength of 13 to 17 tons per sq. in. with 1 to 3 per cent elongation. The metal is non-magnetic and it has a high electrical resistance.

Ni-Resist is used for cast parts subjected to high temperature exposure effects. Typical uses for this alloy include burner parts, soot blower nozzles, furnace doors and grates, superheater tube spacers and hangers, Diesel cylinder heads, and combustion chambers, etc. This metal has also given good results for valve seating inserts in petrol engine cylinders and heads.

" NICROSILAL " CAST IRON

This alloy cast iron is a modern heat-resisting austenitic one and contains about 18 per cent nickel, 6 per cent silicon, 1·8 per cent (total) carbon, and 1 per cent manganese ; a harder variety of Nicrosilal contains up to 3 per cent of chromium in addition. This metal has a marked resistance to "growth" and corrosive effects or "scaling" and possesses good ductility for a cast iron. As a result it is not liable to cracking when suddenly heated or cooled. It can be cast into sections less than $\frac{1}{8}$ in. thick, the resulting metal being free from white or mottled iron. Nicrosilal is easy to machine and it gives a good surface finish; the latter can readily be burnished. It is non-magnetic also. The tensile strength is about 16 tons per sq. in. with 3 per cent elongation. The soft grade of this metal has a Brinell hardness of 110, and the harder grade 200 to 250. It has a higher expansion coefficient than normal grey cast iron and a lower thermal conductivity.

Nicrosilal is used for furnace parts and for special ingot and bottle-making moulds. Other applications include superheater castings, furnace grids, annealing pots and furnace fittings. In general it can be used wherever a high resistance to oxidation, growth and temperature effects is required.

" NI-TENSYL " CAST IRON

As its name indicates this is a nickel cast iron of high tensile strength. It possesses good hardness values and can be machined without difficulty. A typical cast iron of this class contains from 2·7 to 2·9 per cent carbon: 1·25 to 1·75 per cent silicon; 2·3 to 3·5 per cent nickel; 0·5 to 1·0 per cent manganese; 0·3 per cent phosphorus; and below 0·12 per cent sulphur. In the heat-treated condition this iron gives a tensile strength of 30 tons per sq. in. and a Brinell hardness of 400. The heat treatment process consists in heating the metal parts to 850° C. and quenching in oil; afterwards they are tempered by reheating to 350° C. and again quenched in oil.

This alloy cast iron is used for all purposes where high tensile strength and hardness. with good machining quality, are required; in this respect the heat-treated grade is machinable as cast. The non-heat-treatable grade is used for large press dies for drop forgings, stampings, etc., whilst the heat-treated iron is employed for making light blanking dies and dies for small presses, etc.

SOME OTHER CAST IRONS

Apart from the special cast irons described, all of which have important industrial applications, there are other kinds of cast irons made by different processes with various compositions for particular purposes. These include the Emmel Thyssen and Piwowarsky irons; the latter is a high tensile iron. There is also a hard grade of cast iron, known as the "martensitic" one, noted for its high resistance to wear. This iron is generally too hard to machine by ordinary steel tools, but it is amenable to machining by tungsten carbide tipped tools. This grade of iron is sometimes used for automobile cylinders on account of its excellent wearing properties. Another type of iron is the high-aluminium one used for heat-resisting castings; it contains about 8 per cent of aluminium and a small proportion of chromium.

Yet another class of alloy cast iron is the *nitrogen-hardening* one, containing 1·5 to 2·0 per cent each of aluminium and chromium. A typical commercial iron of this class which is used for cylinder liners and castings is "Nitricastiron." It is hardened, after machining, by exposure at a temperature of 500° C. to a stream of nitrogen for a period of about 90 hours, when a surface hardness of about 900 (Firth diamond test) is obtained; the corresponding hardness value on the same scale for annealed Nitricastiron is 300.

WROUGHT IRON

Wrought iron, which is sometimes known as puddled iron, is a fairly pure form of the metal. It is soft, malleable, and ductile, and its fibrous character, induced by the elongation, during forging, of the slag which it contains, has made it a most useful material for parts such as chains, railway wagon couplings, hooks, etc., which are required to withstand repeated shocks and stresses of an intermittent character.

Before the introduction of mild steel, or "ingot iron," its use was universal for all kinds of forging work, but its application is now almost entirely limited to the work stated, although a quantity of bolts and rivets is still manufactured from good quality wrought iron.

MANUFACTURE

The method of producing wrought iron is by means of the oxidization of silicon, phosphorus, manganese, and carbon of grey pig, by the influence of oxidizing

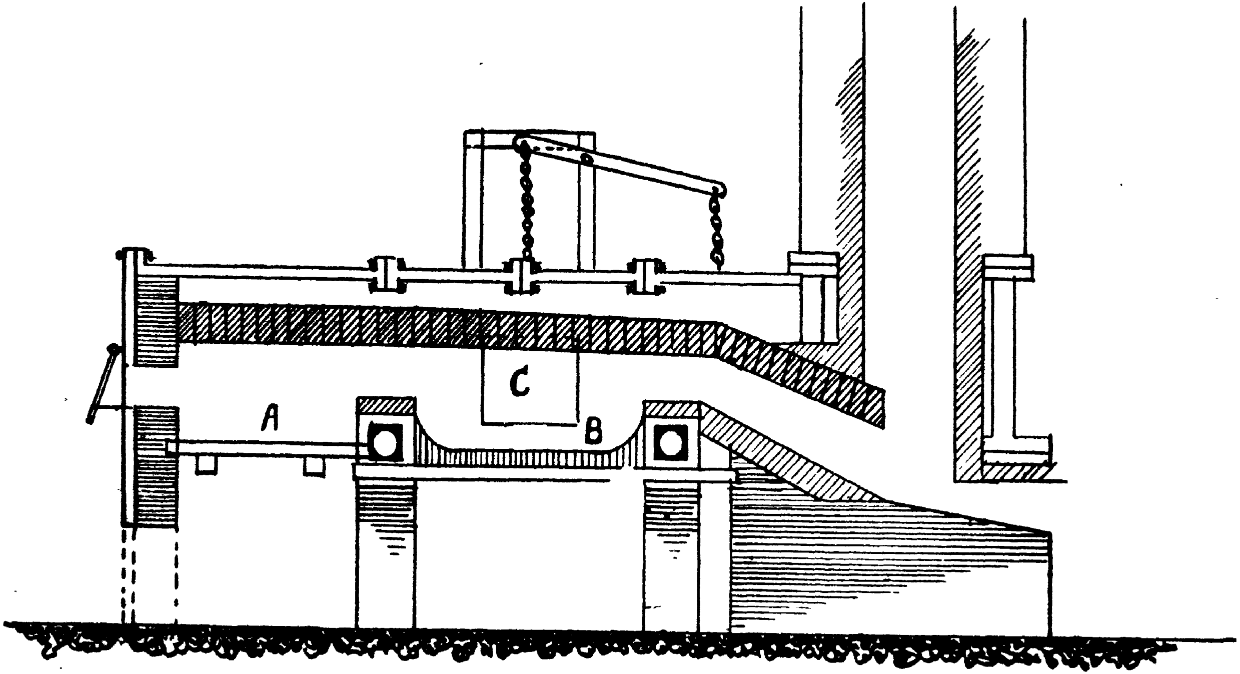


FIG. 27. SECTIONAL SKETCH OF PUDDLING FURNACE

A, Fire-place *B*, Bed *C*, Working door slags and gases. The broken pigs are introduced into the " puddling " furnace, which is of the reverberatory type having a large grate area and is coal-fired.

A section of this furnace is shown in Fig. 27, the hearth being lined with a highly basic and oxidizing mixture of ferric oxide and silica (Bulldog). This is fettled in with " blue billy " (ferric oxide from burnt pyrites), the whole bed softening considerably at working temperatures, and has an important effect in assisting the oxidization of the charge.

The puddling process can be divided into four operations—

1. The melting of the pig, during which a large proportion of the silicon and manganese is oxidized and forms slag.

2. The boiling stage. The molten and partly-refined iron commences to lose carbon which escapes as carbon monoxide (CO), causing a boiling effect to charge. During this stage the slag is well worked into the molten metal to facilitate oxidization.

3. The finishing stage occurs when the carbon has been almost completely removed. The metal stiffens owing to its now higher fusing point, and it is continually broken up into pasty lumps to allow the full oxidizing effect of the slag which runs quite fluid through it. The balance of the carbon and phosphorus is by this means removed together with some sulphur.

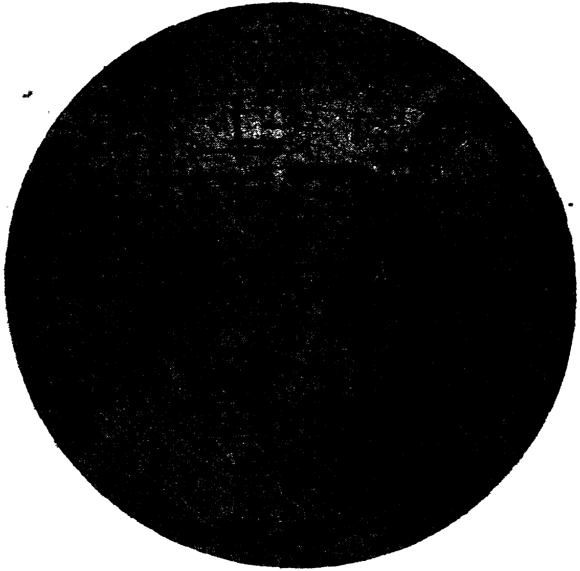
4. The balling stage. The pasty and spongy mass of now malleable iron is gathered together into several balls and removed, dripping with slag, to the " shingling " hammer, and forged out into a rough bloom. The forging operation serves to squeeze out a large proportion of the slag which is trapped in the spongy ball, and to consolidate and weld the iron together. The rough bloom is then passed through the rolls which produce the puddled bar of commerce.

This iron contains much slag which has become elongated by the forging and rolling, as shown in the micrograph (Fig. 28). Better qualities of wrought iron contain less and more refined slag threads, which condition is obtained by cutting up the puddled bar, piling into "faggots," and reheating in a reverberatory furnace to a welding heat followed by hammering and rolling as before. This operation may be repeated several times, mild steel scrap being often introduced into the pile. The micro-structure of a refined iron is shown in Fig. 29. As in the previous photomicrograph, this is from a longitudinal section; the slag fibres when viewed in cross-section appear as round inclusions, as in Fig. 30.

(*Magnified* 50 *diameters*)

FIG. 28. COMMON WROUGHT IRON

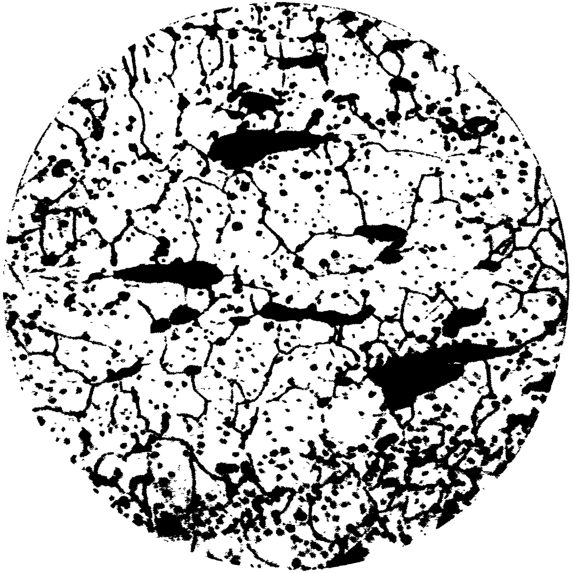
Showing dark slag fibres in a matrix of pure iron (ferrite)



(*Magnified* 50 *diameters*)

FIG. 29. GOOD QUALITY WROUGHT IRON

Refined by piling

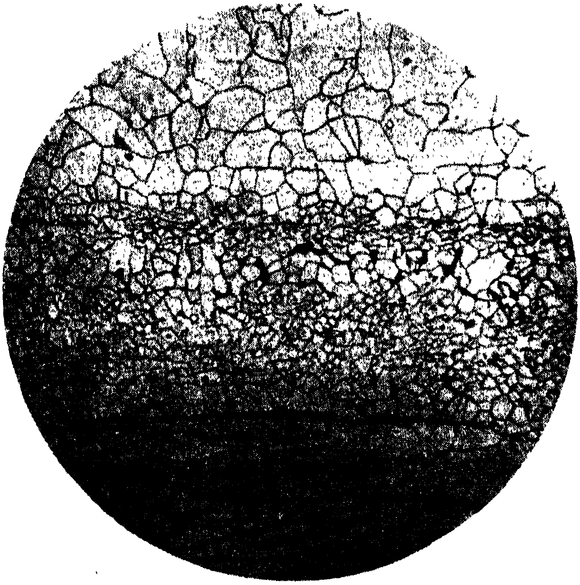


(*Magnified* 100 *diameters*)

FIG. 30. WROUGHT IRON

Showing ends of slag fibres when viewed in cross-section

Swedish charcoal iron is a very pure form of wrought iron, manufactured from white charcoal cast iron low in sulphur and phosphorus by a slightly different system of working in a modified puddling furnace. Its analysis approximates to that of nearly pure iron, and its slag content is very low. A photomicrograph from a Swedish charcoal rod is shown in Fig. 31.



(*Magnified* 50 *diameters*

FIG. 31. SWEDISH CHARCOAL IRON

PURE FORMS OF IRON

For many modern purposes the ordinary wrought and Swedish irons are not sufficiently pure in composition, so that it is necessary to obtain the irons of greater purity by electro-deposition of iron from less pure grades or low carbon steels. The anode consists of the latter irons or steels whilst the cathode receives a deposit of pure iron; the electrolyte often used for this purpose is ferrous ammonium sulphate solution.

A typical percentage composition for electrolytic iron is as follows: Carbon, 0·004; silicon, 0·007; sulphur, 0·006; phosphorus, 0·008; and iron, 99·975. The iron thus produced when annealed from 700° to 800° C. exhibits the typical ferritic structure, although as deposited it is hard and brittle and has a needle-like martensite structure.

The annealed iron has a tensile strength of about 20 tons per sq. in., with an elongation of 40 per cent in the direction of the length of the cathode. A special feature of this iron is the high degree of deformation it will withstand before fracture occurs; tubes of this material can be bent and distorted to a marked extent before cracks appear. Electrolytic iron is employed in electrical work where a high magnetic permeability and low hysteresis are required, but more recently it has been replaced by special iron alloys such as the silicon ones.

Armco iron is another commercial form of pure iron made by the basic open hearth process; it contains only about 0·05 per cent of impurities such as carbon, silicon, sulphur, and phosphorus. It has a specific gravity of 7·866 and tensile strength of 19 to 22 tons per sq. in. in the hot rolled sheet or rod form, with about 25 per cent elongation. Owing to its purity this iron possesses good corrosion-resisting properties and for this reason it is often used in the sheet form for the exposed parts of buildings, for tanks, advertising hoarding plates and signs, etc. It also has a useful application for welding rods used in connection with the oxy-acetylene and electric arc processes.

On account of its ductility it is well suited to press and sheet metal deep-drawing processes and is therefore used in the making of baths, pots, refrigerator parts, and metal spinnings. The metal has a high permeability and low magnetic retentivity and is used for armature core stampings, solenoid plungers, etc. Owing to its toughness it is necessary to provide tools for machining it with rather different cutting and clearance angles than for mild steel and wrought iron. In this connection the front clearance angle for turning and planing should be 15° to 20° and the side clearance 12° to 15°. Armco iron is annealed by heating it to about 850° C. and allowing it to cool slowly in a sand bath or in the furnace itself. The iron is forged at a white heat, i.e. about 1000° C., since it can only be worked with difficulty from 850° to just below 1000° C.

PHYSICAL PROPERTIES

Wrought iron cannot be hardened by heating and quenching in water but slight alterations in its mechanical properties can be obtained by quenching from a cherry red temperature (750° to 800° C.) and then reheating to different temperatures below this value.

The specific gravity of wrought iron is 7·8 to 7·9 according to the grade. A cubic foot of wrought iron of 7·78 specific gravity weighs 486 lb.; a cubic inch weighs 0·281 lb.

The coefficient of linear expansion is $10{\cdot}2 \times 10^{-6}$.

The forging temperature for wrought iron is 850° to 900° C. corresponding to a bright yellow heat.

The tensile strength of wrought iron varies between the values of 16 and 25 tons per sq. in., according to the grade of iron and the direction in which the test is made, e.g. whether across or along the grain. The best grades of sheet wrought iron give tensile strength values of 20 to 25 tons per sq. in. with an elongation of 20 to 25 per cent on 2 inches and a sectional reduction of area at fracture of 50 to 60 per cent; these values are for tests made along the grain. The strength across the grain is usually from 16 to 20 tons per sq. in. Wrought iron has a well-marked yield point of 15 to 17 tons per sq. in. along the grain.

It resists corrosion to a greater extent than mild steel, and is probably preferable to mild steel in cases where shock failure is likely to be induced Its fracture is dark grey and is completely fibrous, but the presence of much phosphorus which it often contains renders the fracture crystalline, as does also the presence of mild steel scrap introduced during the piling operation.

Comparative analyses of wrought iron, Swedish charcoal iron and mild steel are given in the following table, together with their tensile strengths—

Analysis	Wrought Iron	Swedish Iron Charcoal	Mild Steel
Carbon percentage . .	0·020	0·050	0·10
Silicon percentage . .	0·130	Trace	Trace
Sulphur percentage . .	0·022	0·022	0·03
Phosphorus percentage .	0·310	0·007	0·05
Manganese percentage . .	0·080	0·064	0·35
Tensile strength in tons per sq. in.	22·0	20·3	25·0

FATIGUE IN WROUGHT IRON

The term " crystallization due to fatigue " is often used, somewhat erroneously, to describe the crystalline fracture sometimes found on examination of a " fatigued " specimen.

Crystal grains in metals cannot be increased in size without the application of considerable heat, which in the case of wrought iron and mild steel means a temperature of at least 650° C. under extreme conditions. That this temperature is not attained under normal working conditions is obvious, and the cause of the crystalline fracture induced by repeated stresses is purely mechanical.

Crystals usually fracture across themselves along cleavage planes, the boundaries of the grains being the strongest. As these cleavage planes vary in direction from grain to grain the whole structure is remarkably sound. " Crystalline " fatigue fractures, however, exhibit cleavage through a number of grains in the same direction, and when failure occurs it is the fracture along one of these lines of weakness which gives the appearance of large grain facets.

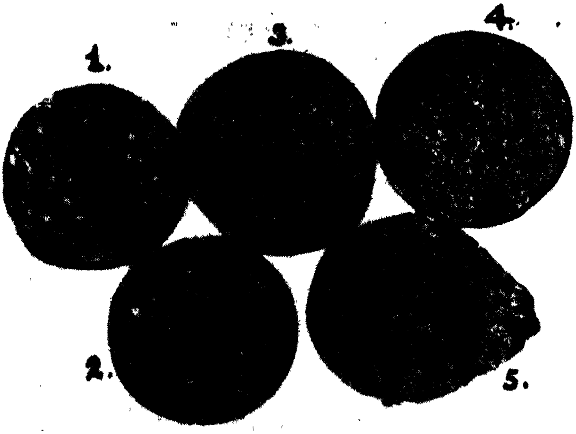


FIG. 32. WROUGHT IRON CRANKSHAFT FRACTURED AT 2-INCH INTERVALS

Showing apparent grain growth

This defect is well illustrated in the case of a gas engine crankshaft which failed in service due to fatigue and exhibited a large grained fracture. The shaft was subsequently broken at intervals of about 2 in. back from the fractured end until the original fibrous condition of the bar was reached. A photograph of the fractures is shown in Fig. 32. This would appear prima facie to show grain growth, but micro-examination of the sections showed lines of incipient rupture decreasing in length and quantity at each section away from the original fracture. Figs. 33, 34, 35 and 36 are taken from the sections marked 1, 2, and 3, and serve to illustrate this point.

Analysis showed this bar to have a high phosphorus content which impaired its resistance to shock. The micrograph (Fig. 36) is from a longitudinal section of the bar, etched with Stead's reagent. This reagent differentiates between pure and impure metal by depositing an adherent film of copper on the purest parts of the polished surface. The phosphorus-rich iron is thus shown white in the figure, which is typical of wrought irons containing much phosphorus.

FAILURE OF WROUGHT IRON CHAIN

Wrought iron still finds some use for the manufacture of chains and cables for haulage and lifting-gear. Owing to its great ductility it is capable of withstanding severe and sudden overloading without fracture, the links being able to elongate and, by deformation in this manner, take up the energy of the load. The ease with which it welds is also an important factor from the manufacturing point of view.

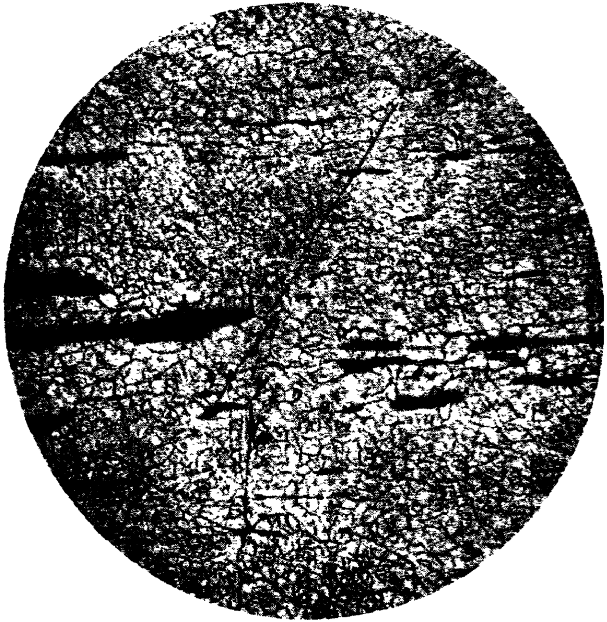
Unfortunately, wrought iron chains deteriorate steadily in service, and failure ultimately occurs, often with disastrous results. The three main causes of failure are—

1. Fracture at the weld.
2. Burnt metal (present in the chain as received).
3. Brittleness due to repeated shock loading.

(*Magnified* 50 *diameters*)

FIG. 33. MICROGRAPH FROM SECTION 1 (FIG. 32)

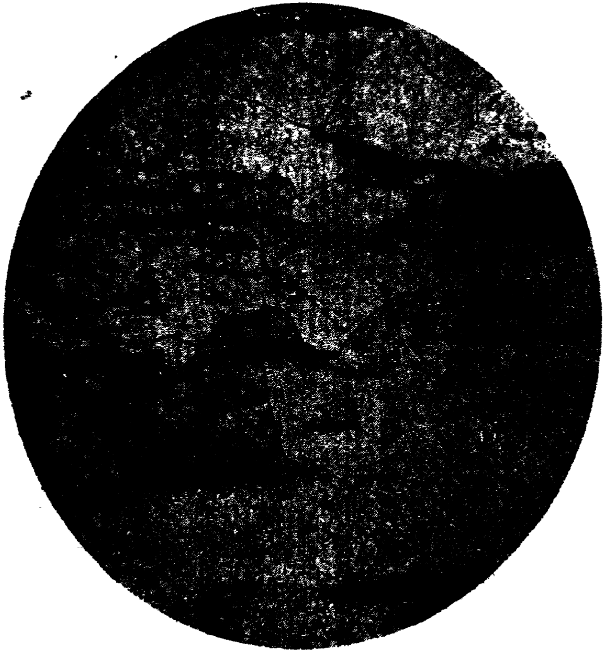
Showing shock lines (Neumann Lamellæ)



(*Magnified* 50 *diameters*)

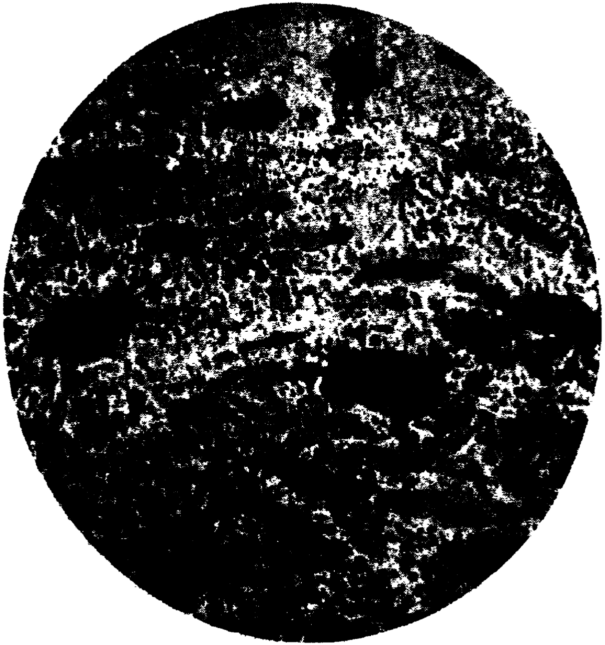
FIG. 34. SECTION FROM FRACTURED END NO. 2 (FIG. 32)

Showing Neumann Lamellæ running through numerous small grains



(*Magnified* 50 *diameters*)

FIG. 35. SECTION FROM FRACTURED END NO. 3 (FIG. 32)



(*Magnified* 30 *diameters*)

FIG. 36. FATIGUED WROUGHT IRON CRANKSHAFT
Etched with Stead's reagent to show phosphorus distribution

WELD FAILURES

These may be due to a defective weld in the first instance. In this case, rupture usually occurs very soon after putting into service, and the fracture has a dirty and incompletely welded appearance.

A much more serious defect is the steady deterioration of sound welds when subjected to the repeated shocks of lengthy service. The incipient weld failure can sometimes be observed on the outside of the link, but when present on the inner surface it often escapes detection until fracture occurs.

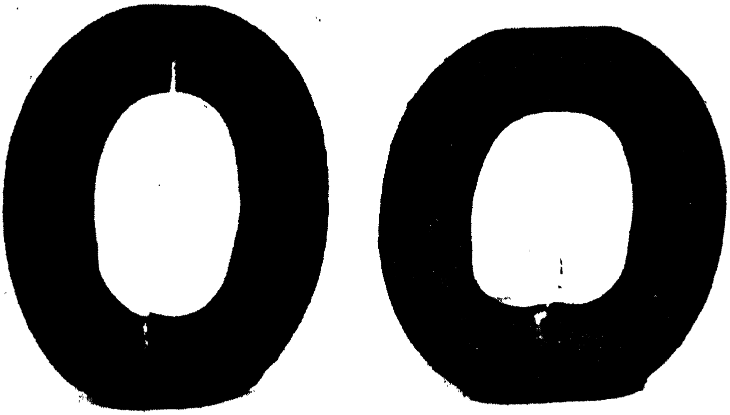


FIG. 37. TWO LINKS FROM WROUGHT-IRON CHAIN AFTER PROLONGED SERVICE

(1) As received
Fractured after two hammer blows

(2) Annealed
Intact after ten hammer blows

Chains which have been in prolonged use may stand the usual static tensile test (proof loading), but fail with a very poor absorption of energy when subjected to shock testing, the weld having deteriorated and been left in a dangerous condition. Such a chain may show no signs of surface flaws, and according to Gough and Murphy ("The Cause of Failure of Wrought Iron Chains," *Engineering Research Special Report*, No. 3, H.M. Stationery Office) no form of heat treatment can restore it or prevent this dangerous condition.

"BURNT" METAL

Contrary to general belief, wrought iron can be readily "burnt" and rendered brittle; the brittleness is not removed by annealing or normalizing.

Gough and Murphy heated four bars of best quality wrought iron to various temperatures, and after notching determined the extent of brittleness by observing the number of hammer blows to produce fracture. Their figures are as follows—

Bar	Temperature of Reheating	Blows Required to Fracture
A.1	1000° C.	7
A.2	1200° C.	4
A.3	1300° C.	2
A.4	1400° C.	1

The fractures showed increasing degrees of "crystallinity" with rise of temperature, and it is therefore obvious that a brittle condition produced during manufacture may have a serious effect on the chain's life.

"Burnt" metal shows a shining crystalline fracture.

BRITTLENESS DUE TO SHOCK LOADING

This is the most common cause of chain trouble, and is induced even in chains which have been subjected to loads very much smaller than the stipulated safe load. When fracture occurs, or when the chain is subjected to shock testing, fracture invariably takes place at the crown of the link and commences at the inside surface.

That chains become brittle in service has long been recognized, and this has led to the established practice of periodical annealings to restore ductility.

Repeated static overloading does not cause the brittleness, as is obvious when the highly ductile nature of wrought iron is considered, and careful observation has shown that the true explanation lies in the hardening of the surface of the metal by inter-link action. This surface hardening is caused by the countless little shock-blows the links give each other when "rattled" over winches, capstans, etc., the snatching of slings and couplings, and the thousand and one impacts imparted during the normal working of a chain.

Fig. 37 is a photograph of two links from a brittle chain: (1) as received, (2) after annealing. These have been tested by placing end-up on an anvil and subjecting to a succession of blows with a sledge hammer. The brittle link shows no ductility, and is not distorted. Fracture took place after two blows at the crown (top) of the link. The annealed link successfully withstood ten blows with the hammer, and the extent of deformation shows that ductility has been restored. Both links, however, show weld deterioration as mentioned previously.

The hardening effect is only superficial, and the interior of the bar is left in the original condition. This brittle skin fractures readily, and the rest of the bar then breaks along the line of weakness thus induced, exactly as if the link had been notched.

It is interesting to note that the skin-hardening effect with its attendant brittleness can be produced in a wrought iron bar by giving it a large number of light blows with a 2 lb. hammer. About 100 blows to the square inch are required to show this effect, which can then be demonstrated by fracturing. If the hardened skin is "turned" off in the lathe, the centre of the bar can be proved to be highly ductile.

This brittleness can be entirely removed by annealing at 650° C., but results superior in general ductility and resistance to impact are obtainable by normalizing (heating followed by air cooling) at about 1000° C.

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